INTERNATIONAL
HELLENIC
UNIVERSITY

Reverse Engineering and Manufacture of Moulds using additive and subtractive 3D Technologies for the Replication of Great Alexander's silver Tetradrachm (336~323BC)

Apostolos Athanasiadis

SCHOOL OF ECONOMICS, BUSINESS ADMINISTRATION & LEGAL STUDIES

A thesis submitted for the degree of

Master of Science (MSc) in Strategic Product Design

January 2020

Thessaloniki – Greece

Student Name:	Apostolos Athanasiadis
SID:	1106170004
Supervisor:	Prof. Dimitrios Tzetzis

I hereby declare that the work submitted is mine and that where I have made use of another's work, I have attributed the source(s) according to the Regulations set in the Student's Handbook.

January 2020

Thessaloniki - Greece

1. Abstract

This dissertation was written as part of the MSc in Strategic Product Design at the International Hellenic University. This thesis covers the aspects of Reverse Engineering and Additive Manufacturing regarding the construction of a mould for Great Alexander's silver Tetradrachm, a coin minted during his reign between 336~323 BC. The coin is located at the Mould Museum of Aristotle University and there the scanning process for obtaining the coin's 3d data took place with the permission of the museum supervisor. The project will be divided in two segments the theoretical part which will describe the theoretical background of all the manufacturing principles regarding the project's structure. Subsequently, the experimental part will follow which will incorporate the forementioned processes and by use of cooperative software-devices depicts the procedure of replicating the coin and creating moulds out of it. The final purpose of the project is to depict the surface differences between the manufacturing processes.

Acknowledgements

I would like to express my deepest gratitude to my supervisor professor, Dr. Dimitrios Tzetzis for his guidance through the whole structure of the project, and in general for his concern during the MSc. I also would like to thanks Manolis Tzimtzimis, the laboratory technician for his valuable contribution regarding the applied software and equipment of the lab and furthermore with the scanning process of the dissertation thesis relevant coin at the mould museum at Aristotle University of Thessaloniki. I would also like to thanks Natalia Kazakidi the museum supervisor at Aristotle

University of Thessaloniki for his kind Finally, I also owe many thanks to my parents for their moral support during my studies.

Keywords: Additive Manufacturing, Reverse Engineering, 3d Printing, Moulds

Apostolos Athanasiadis

January 2020

2. Πίνακας περιεχομένων

1. INTRODUCTION

Mass production of goods and especially products in antiquity was a profound issue which demanded the existence of a mould for producing an object. An indicative example regarding Reverse Engineering for mass production is coin minting in ancient times. For the construction of a coin a proficient mould was mandatory. For vast empires, such as Great Alexander's, several minting workshops were appointed for producing the silver Tetradrachm. In every workshop the mould was engraved by a craftsman and without sufficient information its construction was mostly depended on his abilities. This was the first sort of Reverse Engineering. With the pass of time and due to increase of needs in modern societies the demand for products was getting bigger. The first industrial revolution led to evolution of new manufacturing processes which resulted in an increased number of new firms and eventually in a tremendous increase in mass production. Besides the increase in productivity rates, it had also impact to competition among firms for producing not only functional products, but convenient in use and aesthetically appealing as well. This competition enforced firms to comprehend the way a successful competing product works or constructed in order to attain information about it and enhance it with some additional features. At that time, this kind of espionage took place with firms buying one competing product and dismantling it for deducing its features. The ability of Reverse Engineering to analyze the part either by contact methods but especially with non contact methods made it to be a compatible method in Automotive and Aviation industry, Science and Archeology factors among others. This project is about the construction of a mould for the forenamed coin, the Silver Tetradrachm of Alexander the Great. The coin was minted during his reign (356~323BC) and is now stored in the mould museum of Aristotle University in Thessaloniki. The initial purpose is to depict the procedure of using Reverse Engineering methods for the obtainment of an existing tangible product data with emphasizing the role of non contact methods in Archeology aspects, since most of the archeological findings are likely ought not to come in contact due to preservation reasons. Furthermore the obtained digitized 3d data through NextEngine 3d scanner will be processed and then exported as *stl format in order to be inducted to Meshmixer and be manipulated. Then those manipulated *stl files will be imported to Solidworks for the sake of the mould design. The moulds and the coins will be exported as *stl format once more and will be used later on for the Additive Manufacturing process using two different construction principles, the SLA and FDM process. .Those *stl files will be imported in two slicing software, Cura and Preform by which the construction gcode will derive. The printed moulds and coins ,a total number of 7 items will be subjected again in scanning process with NextEngine scanner and those scans after data process will be again exported as *stl format files .Again will be imported to Meshmixer for mesh manipulation of the scanned data. The final aim of the project is the subjection of the three coins and four dies to deviation analysis with use of Artec Professional+ 11 .

2. REVERSE ENGINEERING

In this chapter the aspects of Reverse Engineering as part of the process to replicate or enhance an existing product by obtaining information as 3d data with use of scanning methods will be described . Furthermore, the manipulation process of those data with NextEngine Scan Studio will be presented and finally they will be exported at a comprehensible format in order to be used by CAD software

2.1 How Reverse Engineering Can Be Defined?

Engineering, in general, is defined as the procedure of mind mapping, designing, constructing, assembling and maintaining a new product. Engineering can be divided in two main categories, forward and reverse engineering. Forward Engineering is the traditional process of producing a product/good that will be based in a sensible design, satisfactory technical details (bill of materials, drawings etc.).For some occasions though when a physical product has to be duplicated without existence of sufficient data for its construction the process is then called Reverse Engineering. Due to the fact that Reverse Engineering is a very reliable process for obtaining the part's geometry by use of 3d points, is widely used in several factors in the industry. Until now, the traditional way for espionage and reveal the features of a competing product was to buy one and dismantle it something that with reverse engineering there is no need to do so. For instance, it should be taken into consideration that most of the prototypes in automotive industry are made out of clay, plaster etc. , but for the production of a part a CAD model of the prototype is mandatory. With the advance of products regarding their shape, a design made through CAD isn't sure that will replicate exactly the prototype. So, Reverse Engineering is the most suitable technique for replicating a product due to the fact that the original object itself is the source information for the CAD model.

2.2 Reverse Engineering (RE) as generic process

Reverse engineering is an approach for the analytical presentation of an existing product regarding its dimensions, design and contours and helping by this way a designer to enhance the existing product with some improvements. The resulting information assist on the evolution of the product regarding re design processes.RE consists of four stages:

- ❖ **Data evaluation:** visual inspection and quality evaluation
- ❖ **Generation of data**: CAD modeling and engineering drawings
- ❖ **Design verification:** prototyping, model testing and failure analysis
- ❖ **Prototype implementation:** prototype implementation and economic analysis

Reverse engineering serves the cause of redesigning an existing product during which is evaluated regarding its functionality, assembly-disassembly, the manufacturing methods used etc. For the collection of surface data two methods can be adopted and divided in two main categories:

- ❖ **Contact methods:** Contact methods as a traditional way of obtaining data requires physical contact between the desired surface and the device for measurement.
- ❖ **Non contact methods:** The most common use of non contact methods involve laser or light as the mean of transforming the points to coordinates. Non contact methods can be further divided to active and passive techniques. Active techniques are applicable for two categories, spot ranging and structure lighting. Passive techniques implement the use of ambient light and are divided in three groups:

  a. **Stereo scanning**
  b. **Range from texture**
  c. **Range from focus**

2.3 Computer Aided Engineering (CAE)

The term Reverse Engineering (RE) can be comprehended in various ways by many people. Computer Aided Engineering (CAE) is the full automation of Reverse Engineering. In the late ‘70s and especially in the 1980s Computer Aided Design (CAD) models started to prevail in the fields of engineering. The absolute dominance of (CAD) models came with the structure of Boeing 777 in the 1980 due to the fact that the whole plane was designed through CAD process. This revolutionary technology continued in the ‘90s and nowadays is accompanied by the emergence of Computer Aided Manufacturing (CAM).Computer Aided Manufacturing is the sector of manufacturing process where Computerized Numerical Control (CNC) machines are fabricating objects related to a CAD model.CAM gives the designer the ability to visualize a conceptual CAD model and transform it to a tangible product.

2.4 Computer Aided Reverse Engineering (CARE)

Computer Aided Engineering via CAD and CAM technologies is the combination of modeling and fabrication, meaning that a conceptual product was modeled through CAD software and fabricated through CAM machines and technologies in a real everyday product. CARE has the opposite principles compared to CAE principles.

2.5 Scanning Process

The scanning phase includes the right technique, customization of the parameters (object's position, light etc.) and the scanning of the desired object. With scanning process the geometry of the part is captured in a "cloud of points" grid and these 3d data consist the geometry of the part. For the scanning execution two ways are available:

a. **Scanning with contact methods**

b. **Scanning with non contact methods**

2.6 Scanning with contact methods

Contact scanners rely on the use of contact probes which are used for the transition of the object's features to the computer because the probes are following the contour of the surface. During scanning, contact pressure between the probe and the surface takes place so that the probe can obtain a point. This contact pressure is automatically a limitation for the use of contact scanners especially when the scanned surface is made out of soft and tactile materials. As it's understood, scanning with these contact probes is a very precise procedure and the Coordinate Measuring Machines (CMM) - with which the contact probes are equipped - are accounted for these accurate measurements.

2.6.1 Coordinate Measuring Machines (CMM)

These measuring devices enable engineers to obtain accurate dimensions, lengths or other intricate features from an object with their precision ranging in between +0.01 and 0.02 mm. This process is done manually and involves a significant amount of effort for intricate objects. Before the induction of CMM machines the measurement of an object's features was made by calipers. CMMs were inducted in the early '60s as an alternate method for measuring an object.

2.7 Scanning with non contact methods

For non contact scanning a variety of technologies exploit scanning with no physical contact between the scanner and the object. These devices make use of optics, lasers and charge coupled sensors which are capable of capturing a huge amount of point data very fast. Despite that, non contact scanners suffer from some flaws.

- The typical tolerance of non contact scanning is in between the range of +/- 0.025 and 0.2 mm
- There is a significant defect with scanning surfaces which are parallel to the cognitive axis of the laser
- Light is a significant factor for non contact scanning process, thus, different scan data on blurry or dark surfaces compared to shiny ones. So, it's strongly recommended that shiny surfaces should be coated with powder before scanning so that the laser to be enabled to capture more 3d data.

2.7.1 Laser scanning and Laser Triangulation

Laser scanning belongs to the active techniques for obtaining accurate scan data. Laser scanning with spot ranging method, enables the large acquisition of data during scanning. The laser scanner "fires" a beam into the desired surface and the reflected beam provides information to a coaxial placed to the beam source. The source location gives the x-y coordinates while the z coordinate derives by the analysis of the reflected beam by the triangulation process as shown at Fig.1.

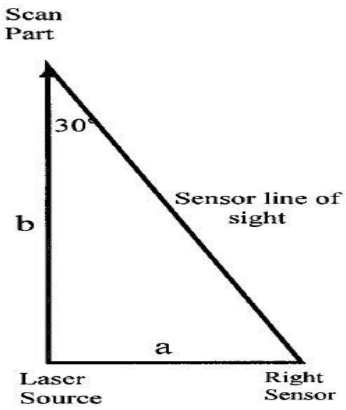


Fig 2.1 The triangle formed between the laser, the scanned part, and the sensors, which provides the geometry to obtain the depth coordinate

2.8 Point processing with cooperative software

The phase of point processing involves the induction and illustration of 3d ”point cloud” data on a computer screen. During this phase, variable scan data can be sufficiently merged together. Occasionally, multiple scans from various angles are required so that all the information of the scanned object is captured. For this purpose, the rotation of the part to its cognitive z axis is required. Multiple scans of the part enable the user to merge the scans effortless and more effective and at the same time avoid errors that have to do with merging. After some additional procedures, such as, trimming, reduction of noise etc, the outcome will be a knit well merged point cloud data exported in the desired format

2.9 Next Engine Scan Studio and Meshmixer

At the following sub-chapter a presentation regarding the scanning process with use of NextEngine 3d scanner and the manipulation of the scan data with use of

ScanStudio will be presented. Furthermore, a presentation for Meshmixer, another program used for manipulating 3D models will follow.

2.9.1 Introduction to NextEngine Scan Studio

The application preferences dialog is available from the “edit preferences” option and is utilized for the customization of scanning (Fig 2.2).

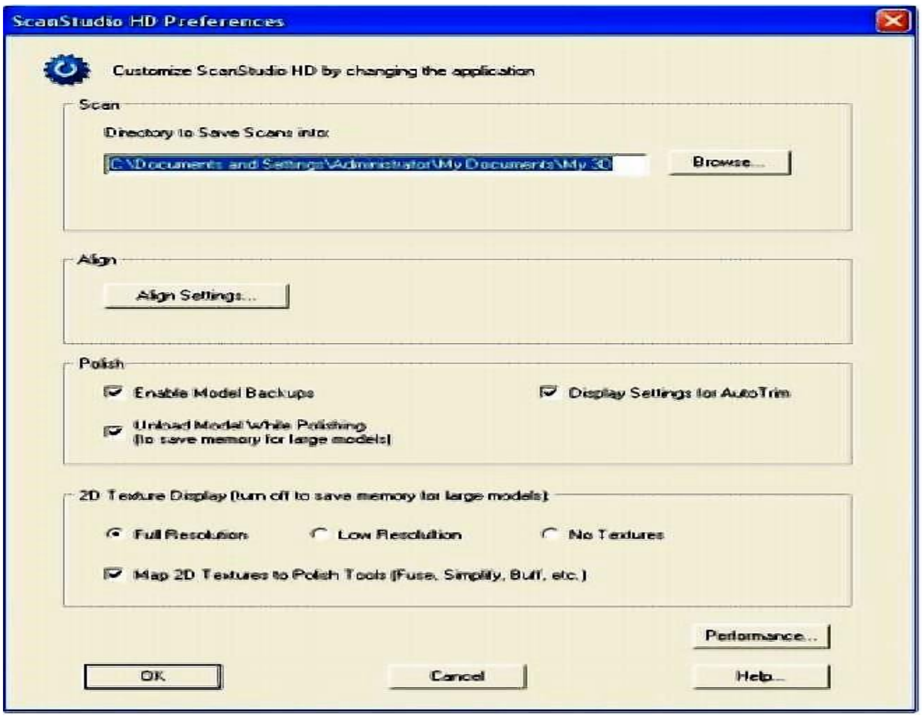


Fig 2.2 Scan Studio Preferences Tab
Ref. Screenshot taken by NextEngine Scan Studio

❖ The “Directory to save scans” option enables the change of the path directory (Fig.2.3)

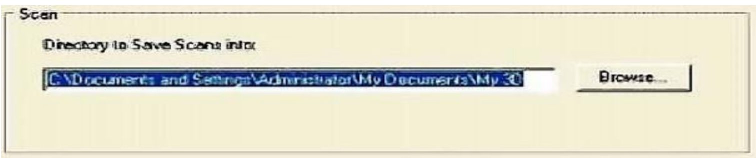


Fig.2.3. Path directory option
Ref. Screenshot taken by NextEngine Scan Studio

Align settings: Modification of the align settings enable the software to merge subsequent faces without the interference of the user (Fig 2.4)

Fig.2.4 Align settings option
Ref. Screenshot taken by NextEngine Scan Studio

2D Texture Display: gives the ability of model backups, display settings for auto trimming (Fig 2.5)

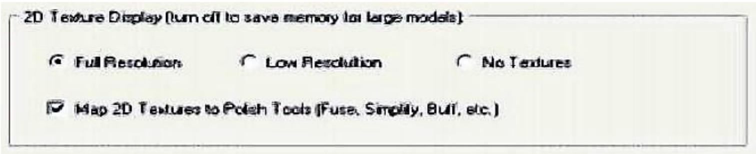


Fig 2.5 2D Texture Display option
Ref. Screenshot taken by NextEngine Scan Studio

Surface preparation

For scanning dark, shiny, transparent or semi transparent objects different settings must be applied in each case for helping the laser of the scanner to capture more data and get the best results (Fig 2.6-2.7)

Fig.2.6 Washable paint pens
Fig.2.7 Use of talc powder
Ref. Screenshots taken by NextEngine Scan Studio

Preparation of the scanning base

The rotating bed of the scanner upon which the desired objects for scanning are placed consists of a rotating base, a gripper in rod form attached to the rotating bed by the help of one out of 4 threaded holes placed at each corner of the bed's contour(Fig 2.8) and a platter which is attached upon the gripper with a tightening-un tightening screw and is allowed to move at the cognitive z axis, adjusted at the right height for facilitating the laser capture procedure(Fig 2.9).The back side of the bed is equipped with a usb cable slot enabling the connection of the bed with the software(Fig 2.10-2.11).

Fig 2.8 .The attachment of the gripper on the scanner's bed

Fig 2.9 The attachment of the platter upon the gripper

Fig 2.10-2.11.Connection of the rotating bed with the scanner
Ref. Screenshots taken by NextEngine Scan Studio Manual

Scanning set up modifications

After the preparation of the rotating bed the device is ready to perform by activating Scan studio (Fig 2.12)

Fig 2.12 Scan button
Ref. Screenshot taken by NextEngine Scan Studio

By pushing the green scan button a pop up window on the computer screen illustrates the preface settings of the software according to the scanned object (Fig 2.13-2.14-2.15).

Types of scan

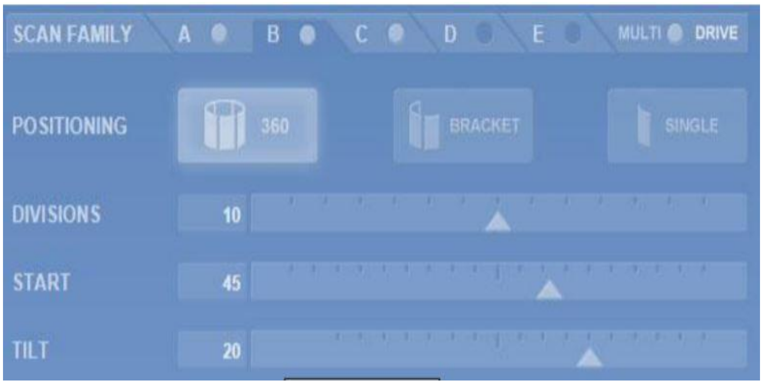


Fig 2.13 Type of scan
Ref. Screenshot taken by NextEngine Scan Studio

❖ With the "360" scan option selected the object will be scanned from every angle.

- The number of divisions will control the degree of rotation between scans and the total number of scans
- The individual scans will be grouped as a family.
- The base will always rotate through 360 degrees in this mode, the number of rotations of the base though is defined by the number of divisions set up. The laser will scan once per division. This has a minimum of 4 and a maximum of 16 divisions
- Start tool bar in 360o mode defines the number of degrees from 0 in which the sample takes the first scan at. 0 is equivalent with the front of the base facing the scanner directly, while everything else is an angle away from the

scanner. This is expressed as number of degrees, from 0 to 180o. Positive angles are expressed with counterclockwise rotation.

❖ With the "bracket" scan option selected the scan will occur in three consecutive angles.

- The number of divisions will control the degree of rotation between scans
- The three scans will be grouped as a family.

❖ With the “single” scan option selected the scan of the object will take place only from one angle meaning that the program will conduct one scan at one single rotation angle which will be defined by start and a single tilt sliders

❖ The tilt slider defines the angle of the tilt that the scan will be conducted. This can vary between a single scan or a set of scans in which the base rotates and every scan family is set up at a single tilt. Tilt starts at 0, as indicated by the number on the left side of the slider, and can be vary between -35 o to +45 o from 0.

Scan Studio HD-HD Pro

At this tab the amount of obtained data can be defined. This amount is interrelated with scan time. Furthermore, the resolution and the type of object to be scanned can also be modified (Fig 2.14)

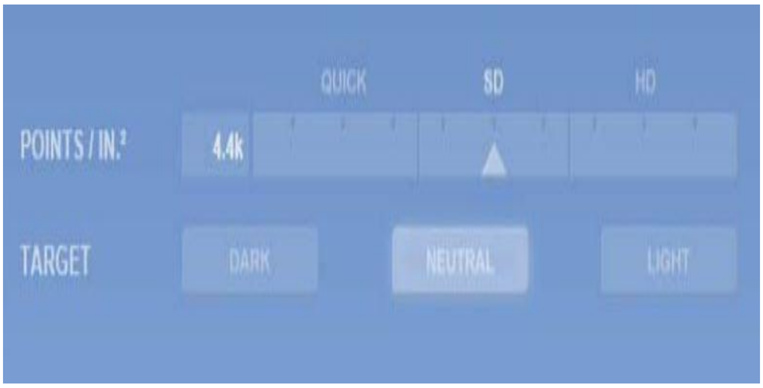


Fig 2.14.Settings for the amount of obtained data
Ref. Screenshot taken by NextEngine Scan Studio

- ❖ With the slider at the settings tab the number of required data per square inch is configured

- ❖ With target option there can be a modification regarding the object to be scanned, thus the target will be set to dark if the scanned object is dark whilst light mode will be chosen if the object is shiny

With three available scales of resolution the scanning could be adjusted accordingly

- ❖ Fine or HD Speed is used for the greatest resolution.

- ❖ Quick Speed is chosen for capturing data the quickest with lowest resolution

Precision

The range tab enables the control of the scanning range defining the position of the object compared to the scanner (Fig. 2.15)

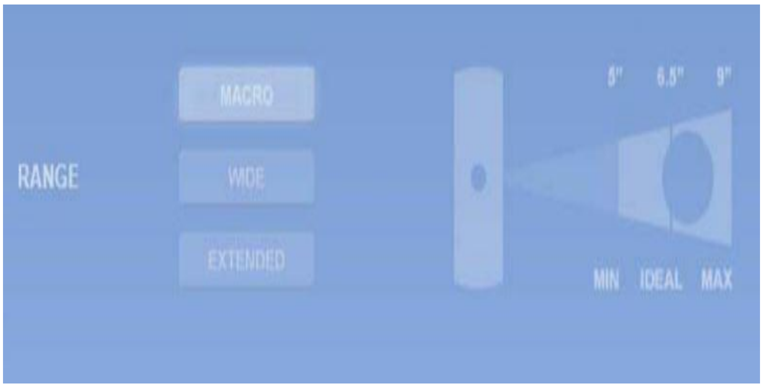


Fig 2.15 Range tab with three variables regarding the distance of the scanned part from the scanner
Ref.Screenshot taken by NextEngine Scan Studio Manual

- ❖ With macro option selected the distance between the object and the face of the scanner should be approximately 17cm

- ❖ With wide option selected the object should be placed away from the scanner's face at an approximate distance of 40cm

- ❖ With the extended view option selected the optimal distance between the scanner and the object should be in between 70 and 80 cm

2.9.2 Manipulation of scanned 3d data

Point processing is the subsequent stage of the scanning process. When the scan procedure is over those obtained data are about to be manipulated through Scan

Studio in order the object's scan to be aligned, trimmed and fused so that the desired file format can be obtained.

Trimming

With trimming procedure unwanted portions of data obtained by the scanner will be removed. The icon for the trim operation is the pair of scissors. By pushing the scissors icon the trim option will be activated (Fig.2.16).

Fig. 2.16 Enabling trimming option
Ref. Screenshot taken by NextEngine Scan Studio Manual

When the trim command is active a pop up window illustrating the trimming tools will be enabled as shown at Fig 2.17.

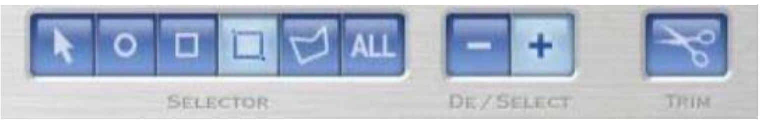


Fig 2.17 The Trim toolbar
Ref. Screenshot taken by NextEngine Scan Studio Manual

The selector Tab enables the user to select one of the various shapes for transforming the mouse pointer and used as trimming tool

The two icons "+/-" are provided for enabling the mode of trim.The + icon is used for marking points that will be erased. For removing the undesired portions the desired trimming shape will be chosen and the "+" button will be activated and the targeted sections will be indicated in red. The – icon provides the ability of undo a false marking


The trim icon enables the trim execution

2.9.3 Object’s scanned data manipulation

The scanned data of the part are imported in Scanstudio as shown at Fig 2.18

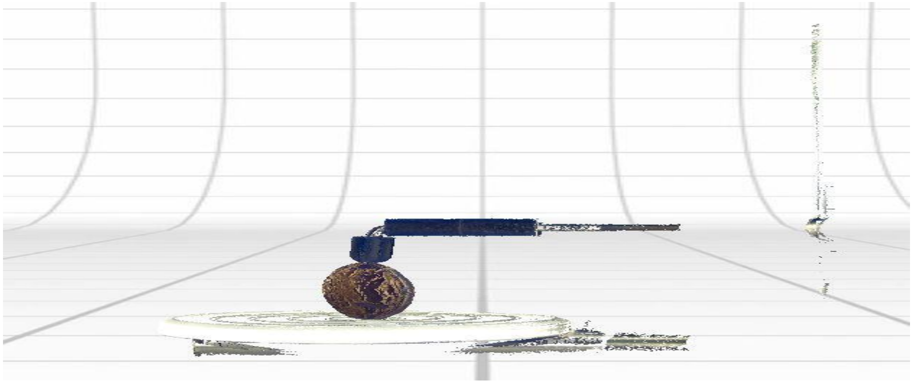


Fig 2.18 Import the object on Scanstudio
Ref. Screenshot taken by NextEngine Scan Studio

The laser during scanning obtained besides the needed data (coin surfaces) unwanted portions of data also such as the bed platform of the scanner.For trimming these portions and lighten the file size the trim command will be activated and the trim selection at the subtabs will be enabled.The unwanted portions are marked and appeared in red color as shown at Fig 2.19.

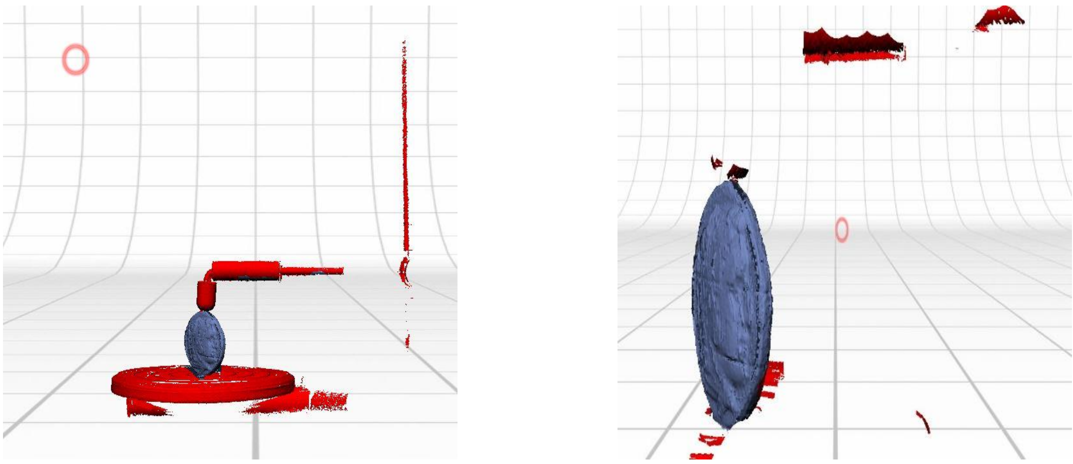


Fig 2.19 Selection of unwanted portions of scanned data for trimming
Ref. Screenshots taken by NextEngine Scan Studio

The trimming process will be repeated for the final noise elimination as depicted at Fig 2.20.

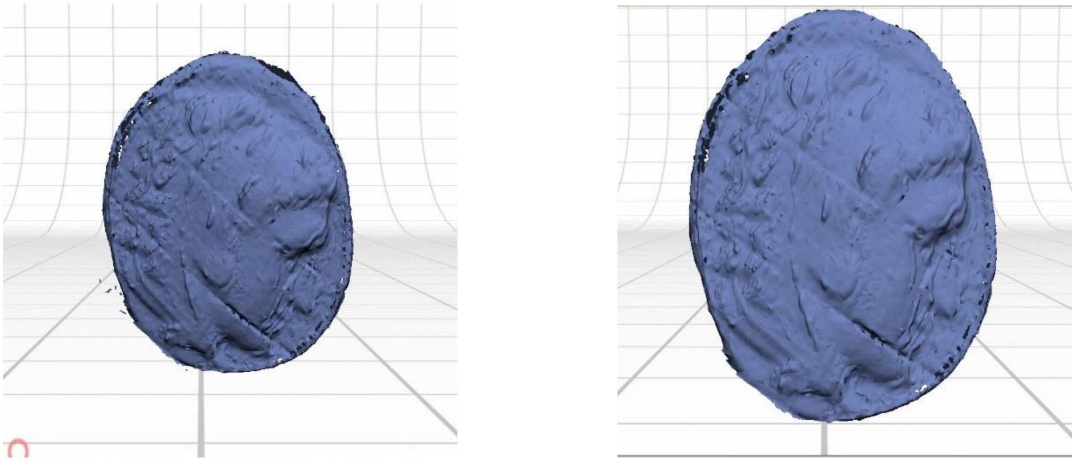


Fig 2.20 The final noise elimination
Ref. Screenshots taken by NextEngine Scan Studio

With the noise eliminated the scans can be subjected to alignment so that a single family of scan to derive.

Alignment

This phase enables the user to align the multiple scans came from scanning stage by use of incorporated tools provided by the software for this purpose. Align option requires the emplacement of pins to similar obvious points upon the scans and results to a conjunction of those multiple scans in one scan. By pushing the align icon the Align command will be activated (Fig.2.21).

Fig 2.21 Align command enablement
Ref. Screenshot taken by NextEngine Scan Studio

The model can be renamed by the yellow bar as shown at Fig 2.22.

Fig 2.22 Model rename bar
Ref. Screenshot taken by NextEngine Scan Studio

With the Align command activated the screen is split in two, and two identical spaces with the first scan families of the coin will appear as shown in Fig 2.23.

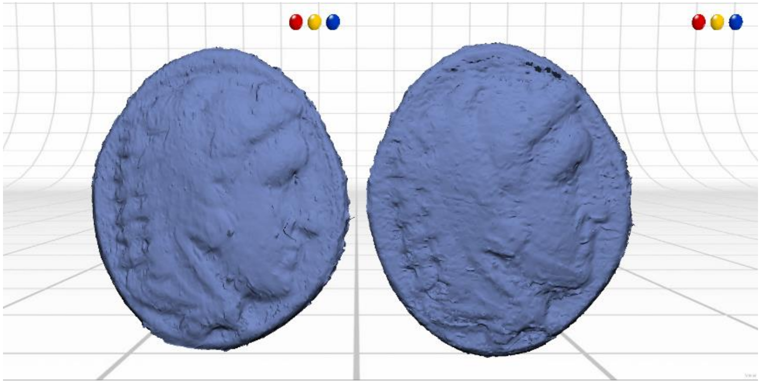


Fig 2.23 The initial Interface of Align command
Ref. Screenshot taken by NextEngine Scan Studio

For proceeding with the alignment some pins should be placed at obvious points of the object which are the common entities in every scan family and will be used for stitching the multiple scans together. The minimum amount of pins to be placed so that the align command to be performed is minimum three as shown at Fig.2.24-2.26-2.27.

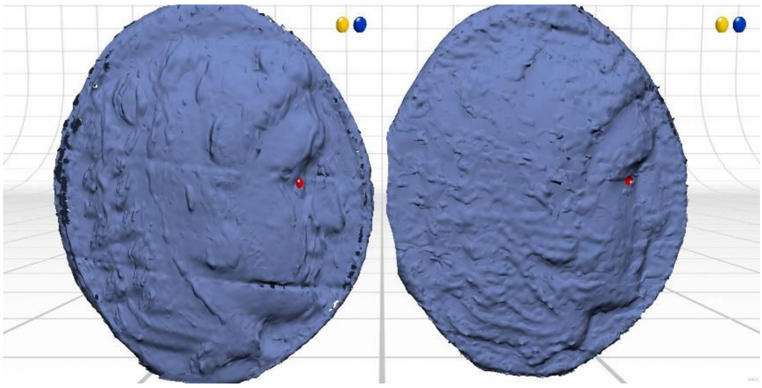


Fig 2.24 Emplacement of one pin
Ref. Screenshot taken by NextEngine Scan Studio

When the first pin is placed the yellow box in the horizontal toolbar will show the number of pins placed on the object as shown at Fig 2.25.

Fig 2.25 Number of placed pins
Ref. Screenshot taken by NextEngine Scan Studio

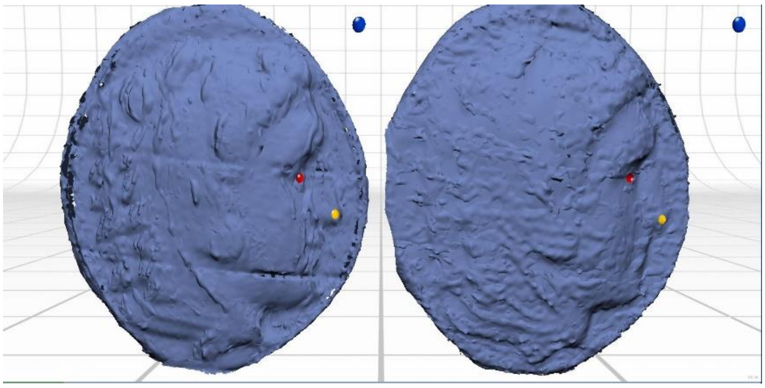


Fig 2.26 Emplacement of two pins
Ref. Screenshot taken by NextEngine Scan Studio

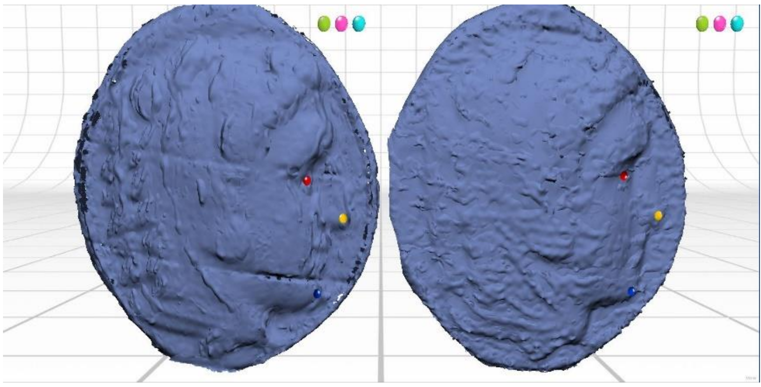


Fig 2.27 Emplacement of three pins
Ref. Screenshot taken by NextEngine Scan Studio

With the emplacement of the third pin the information tab notify us that the align command can be performed as shown at Fig 2.28.

Fig 2.28 Emplacement of 3 pins for the alignment
Ref. Screenshot taken by NextEngine Scan Studio

Fuse

With the scanned faces trimmed and aligned the next step is the fusion of those multiple scan families in one. By the Fuse button on the main toolbar the Fuse command is activated (Fig 2.29) and the fuse toolbar pops up (Fig 2.30) enabling the settings.

Fig 2.29 Fuse command activation
Ref. Screenshot taken by NextEngine Scan Studio

Fig 2.30 Fuse interface
Ref. Screenshot taken by NextEngine Scan Studio

The toolbar consists of a slider which is appointed for the specification of the wanted deviation tolerance for the decimation. 0.00" simplification won't have any effect on the data but as the simplification slider increases the value of tolerance the model will be simplified and the file size will get smaller. Fusion has the ability of simplification, which keeps more points in intricate areas and fewer points in larger planes. Besides the tolerance configuration Fusion settings gives the ability of automatic manipulation of the align errors ,such as holes, or water tight models, or customizing the resolution ratio and enables blending texture as shown at Fig 2.31.

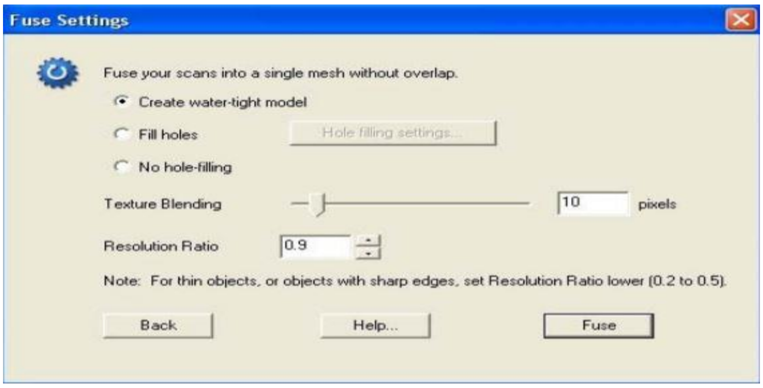


Fig 2.31 Fuse advance settings
Ref. Screenshot taken by NextEngine Scan Studio

For the best inspection of the overlapped surfaces the Hole Filling Slider inspects the circumference size of the holes to be filled. Texture blending is accounted for brightness variations and by a slider the amount of blending textures to be performed is controlled. The Resolution Ratio determines the new average vertice length in relationship to the current one. For the coin the resolution ration was set to 1.0. Values less than 1 will decrease your triangle size. Values greater than 1 will increase your triangle. When the desired configurations regarding fusion are set the process is then performed. as shown at Fig 2.32.

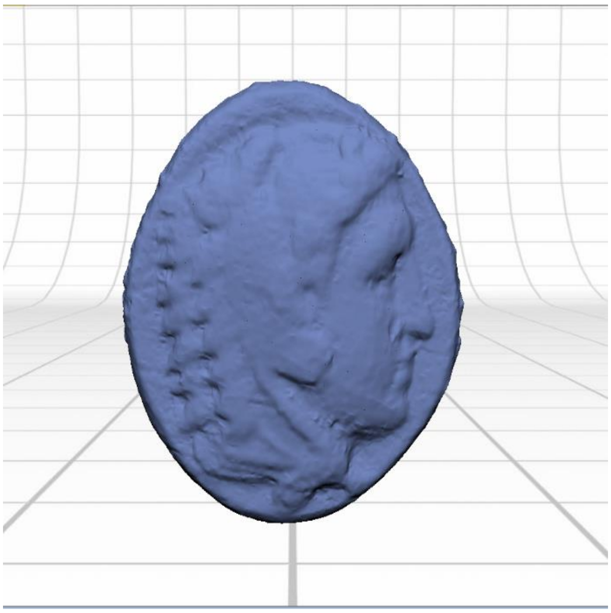


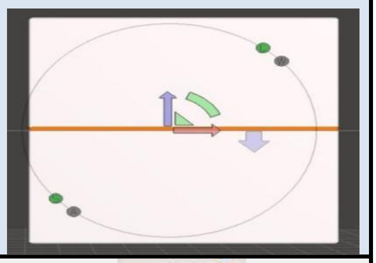
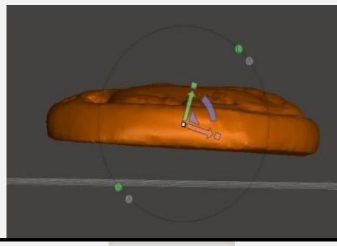
Fig 2.32 The object after Fuse command is performed
Ref. Screenshot taken by NextEngine Scan Studio

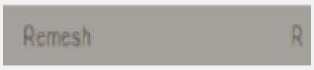
2.9.4 Introduction to Meshmixer

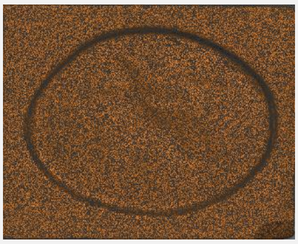
Meshmixer is free software which is not a modeling tool as much but more a manipulating tool for 3D models which are created. It's utilized for the preparation of those models for 3D printing. For the purpose of manipulation the software provides several tools and some indicative but nevertheless important commands are depicted at Table 2.1

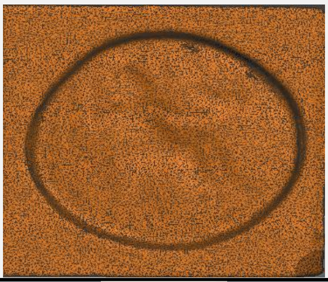
Table 2.1 Indicative commands of Meshmixer

Command	Definition	Procedure	Command deployment illustration
Convert to solid	Convert to solid command creates a solid model which is already inspected and repaired regarding holes an gaps(watertight model)	The command is performed through select option on the main toolbar by selecting the whole object in order to be converted to solid	

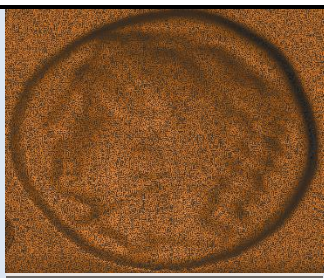
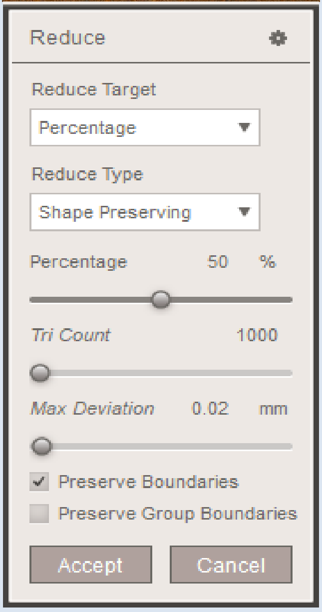
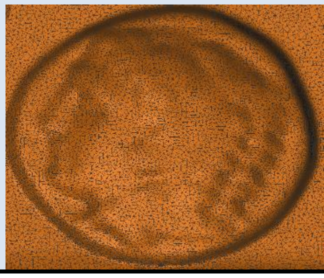
			
Plane Cut	Enables the manipulation of the object by slicing it at predefined regions either by discarding the selected region or by enabling-disabling it by will	The command is performed through the edit option	  
Transform	By transform option the object can be transferred at the x-y-z axis lengthwise	The command is performed through edit option	  
Remesh	Remesh enables mesh simplification by defining the mesh	The command is enabled through select option and in	

<table>
<tr>
<td></td>
<td>density or the length of the edges that consist the mesh triangles</td>
<td>order to be activated the whole object should be selected</td>
<td>





</td>
</tr>
<tr>
<td>Reduce</td>
<td>Reduce is quite similar procedure to Remesh. It enables mesh simplification through reduction of number of triangles or vertices</td>
<td>The command is enabled through select option and in order to be activated the whole object should be selected</td>
<td>


</td>
</tr>
</table>

3. COMPUTER AIDED DESIGN SOFTWARE

As mentioned before Computer Aided Design is the utilization of a computer as a facilitating tool regarding the initial creation of a design, Its customization, the analysis and its optimization. CAD software is used for various reasons, from improving design quality or the communication through CAD documentation or even for improving the designer's productivity.

3.1. Introduction to Solidworks

Solidworks is "Computer Aided Design" software built by Dassault Systems. It is used for design, with integrated analytical tools and design automation to help stimulate physical behavior. Along this chapter the use of such "Computer Aided Design" software will be presented with some indicative but also useful commands. When Solidworks platform is activated a pop up template prompts the selection of mode as depicted at Fig 3.1.

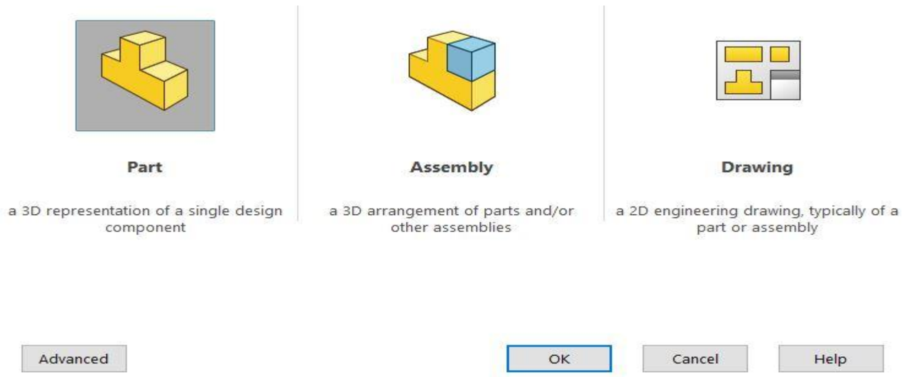


Fig 3.1 Selection of a part to be created or assembly of two or more constructed parts
Ref. Screenshot taken by Solidworks

Solidworks gives the ability of constructing a single part or the splicing of different 3d Parts (Assembly mode).Furthermore the program creates engineering drawings for each part is constructed. By entering the main interface of Solidworks the design tree (Fig 3.2) is present and represents the construction stages of the part. For enabling sketch mode a design plane between the three offered should be activated (Front-Top-Right view) (Fig 3.3).

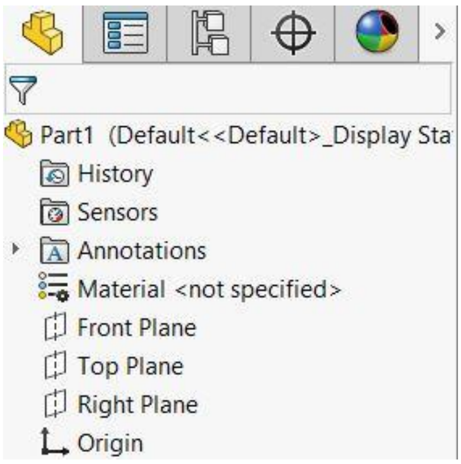


Fig 3.2 Design Tree
Ref. Screenshot taken by Solidworks

By the sketch commands a 2d sketch is designed (Fig 3.4) which after that can be converted in solid part by use of 3d features (Fig 3.5).

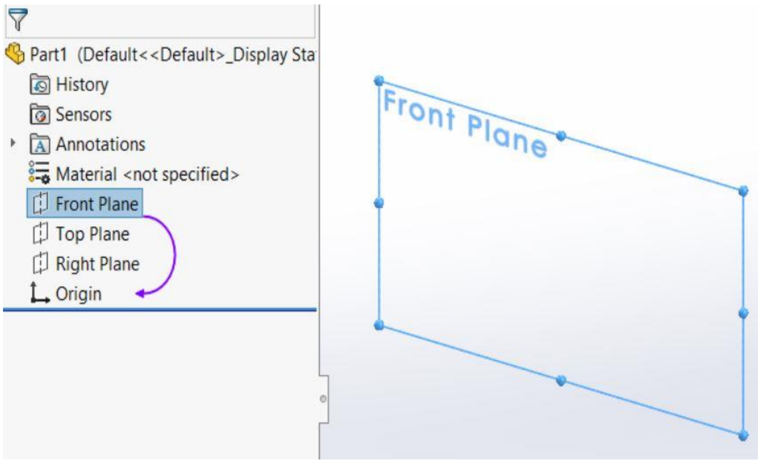


Fig 3.3 Enabling design plane
Ref. Screenshot taken by Solidworks

Additionally a tool bar regarding views modification, appearance, zoom in/out mode, display style, and background is provided as shown at Fig 3.6.

Fig 3.4 2d sketch toolbar
Ref. Screenshot taken by Solidworks

Fig.3.5 3d Features Tab
Ref. Screenshot taken by Solidworks

Furthermore, construction of a part can be achieved by Assembly mode in cases where aren't sufficient design information available for the structure of the new part and is strongly interrelated to an existing part.

Fig 3.6 Display Style, Views, Background
Ref. Screenshot taken by Solidworks

By using the existing part as base feature a new 2d sketch is designed with the design specifications of the base component and can be converted to 3d solid (Fig 3.7-3.8-

3.9). At table 3.1 some indicative but nevertheless useful commands in Solidworks are presented while at Table 3.2 some also helpful 3d features will follow.

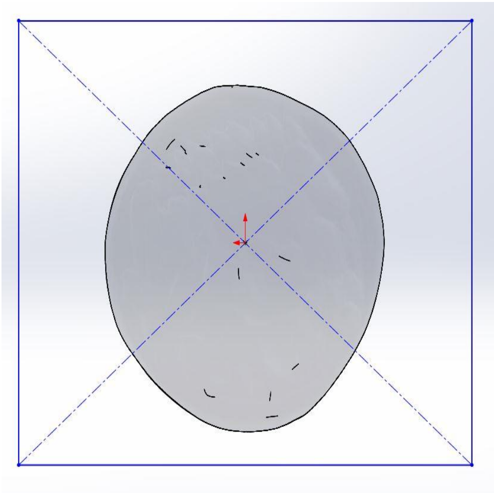


Fig 3.7 New 2d sketch in assembly mode

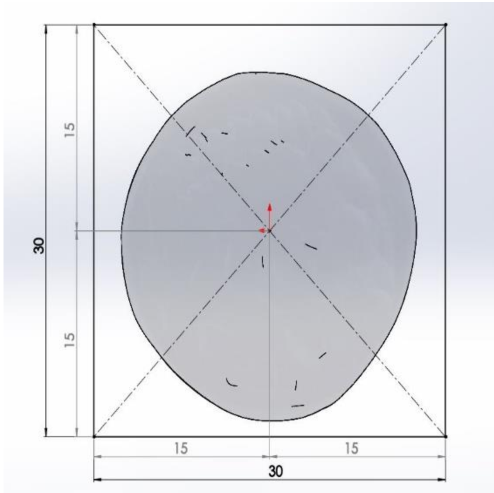


Fig 3.8 Dimensioning based on the base component

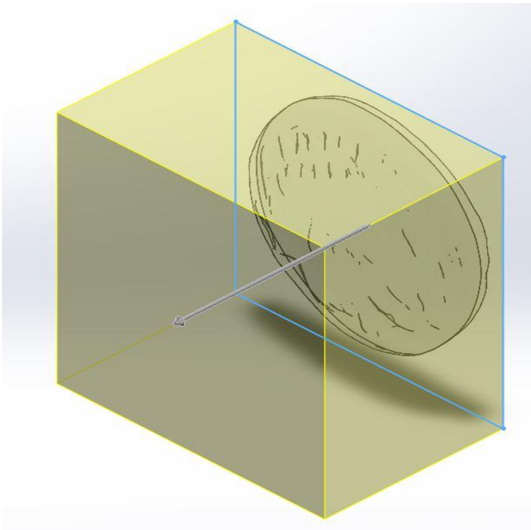
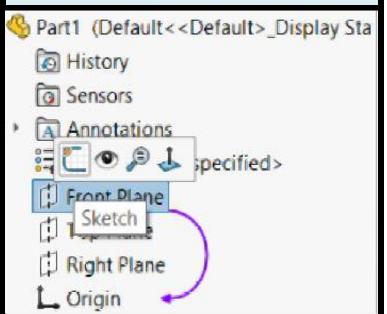
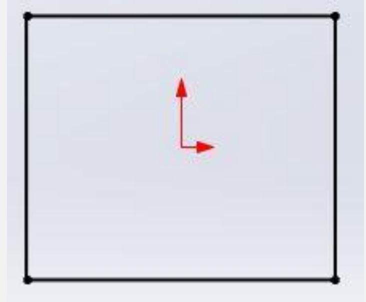
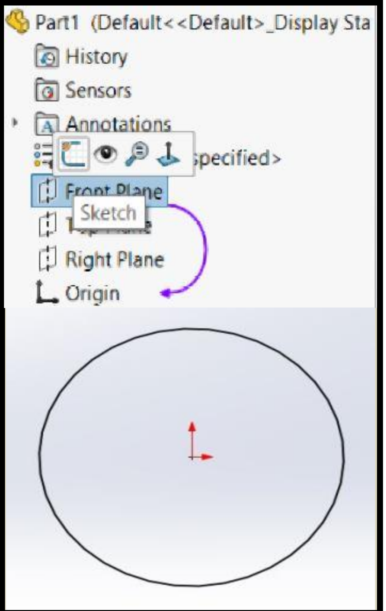
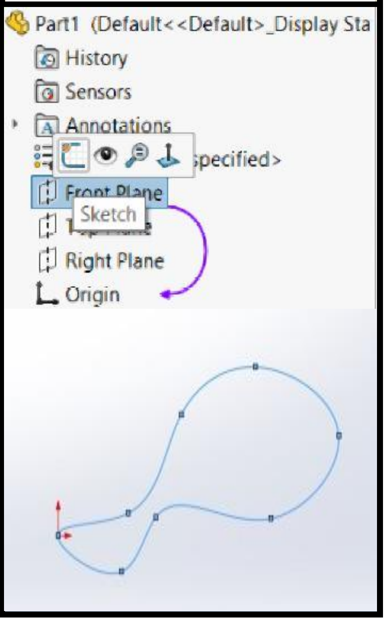
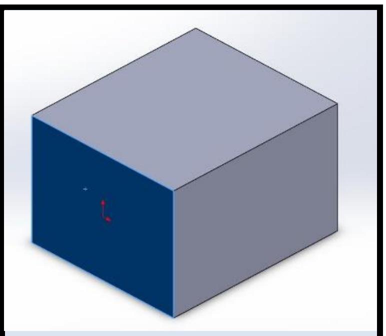
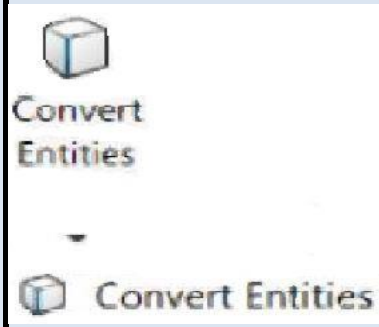
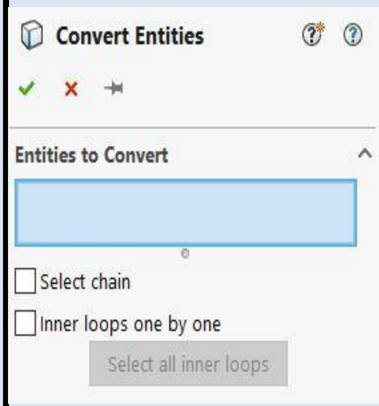
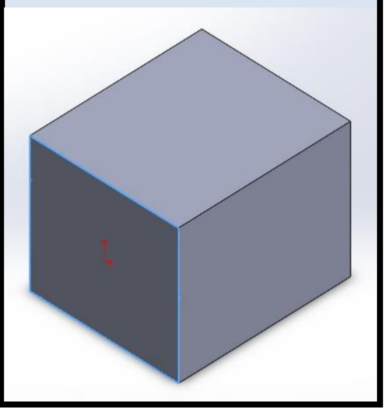


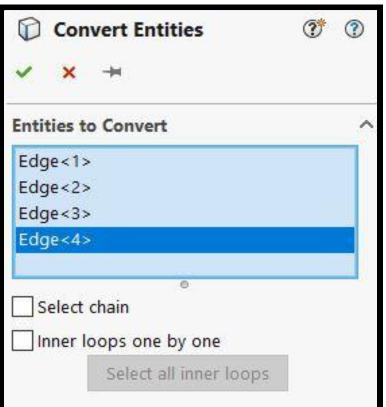
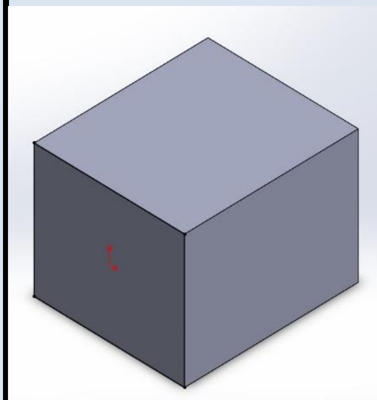
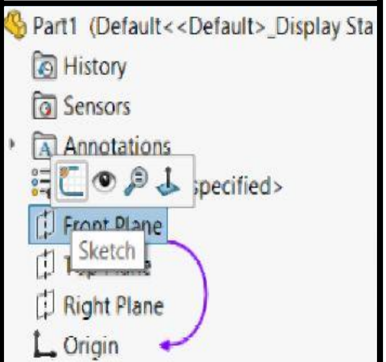
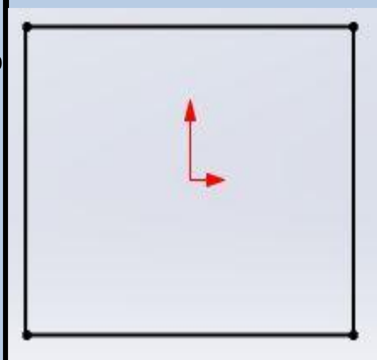
Fig 3.9 Convert the 2d sketch in 3d feature

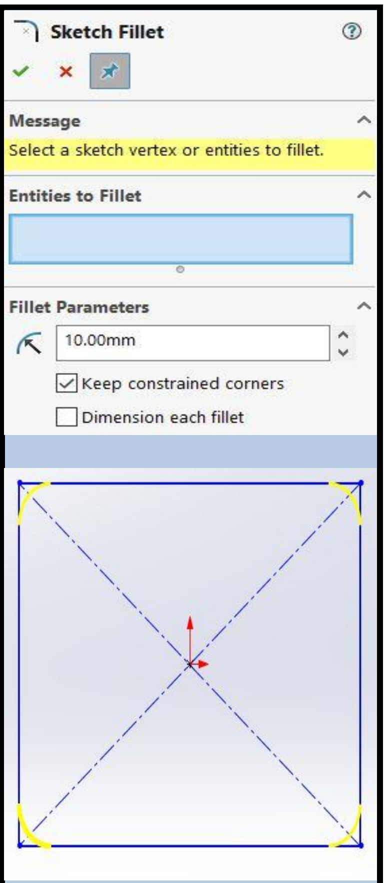
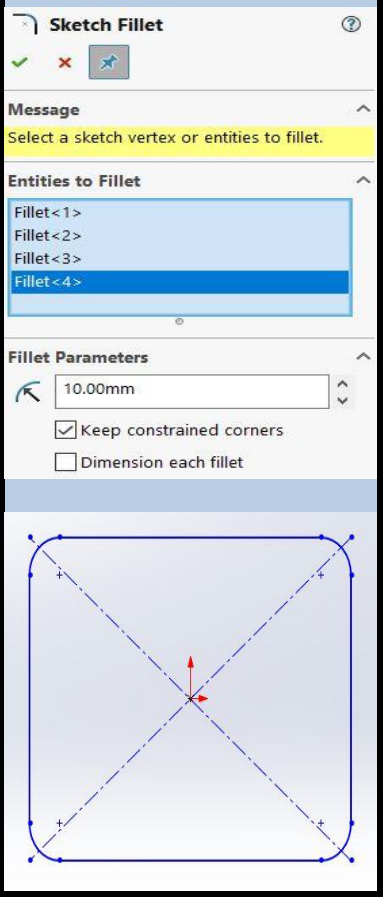
Table 3.1 Indicative 2D sketch commands in Solidworks

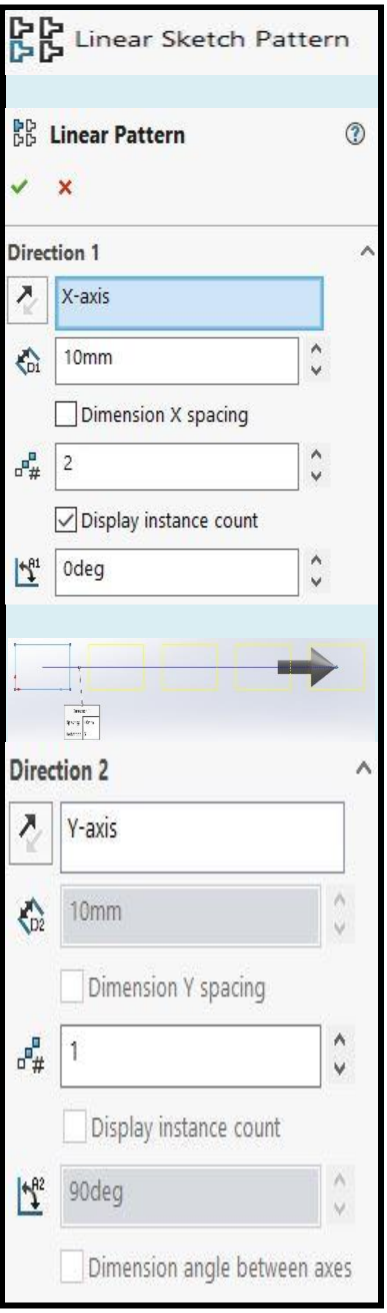
Command	Definition/ Procedure	Command Deployment Illustration
Rectangle	2D sketch of a rectangle /It requires the activation of a design plane	

		
Circle	2D sketch of a circle/It requires the activation of a design plane	
Spline	2D sketch of a spline/It requires the activation of a design plane	

Convert Entities	Transition of a 2D sketch upon a new sketch plane-face/It requires the activation of a face-plane upon which the selected entities will be transferred	   

		 
Sketch Fillet	Creation of fillets on corners or sharp edges/It requires a 2D active sketch so that the command to be performed	  

		Sketch Fillet Message Select a sketch vertex or entities to fillet. Entities to Fillet Fillet Parameters 10.00mm Keep constrained corners Dimension each filletSketch Fillet Message Select a sketch vertex or entities to fillet. Entities to Fillet Fillet<1> Fillet<2> Fillet<3> Fillet<4> Fillet Parameters 10.00mm Keep constrained corners Dimension each fillet

Linear Pattern	It enables the replication of a designed shape along x or y axis	

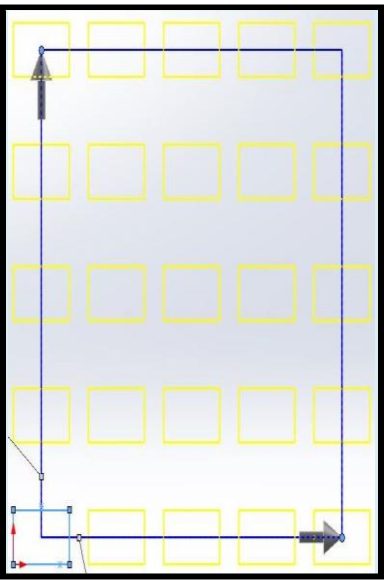
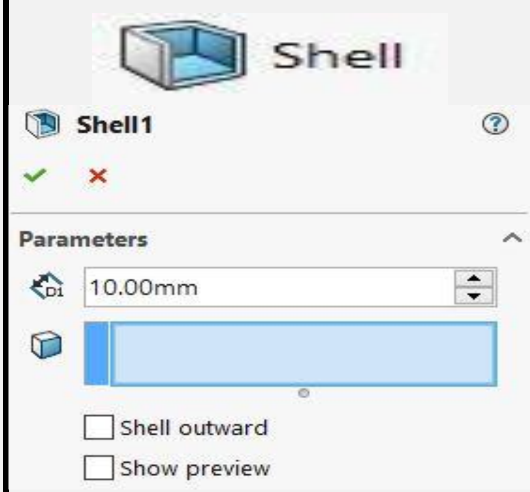
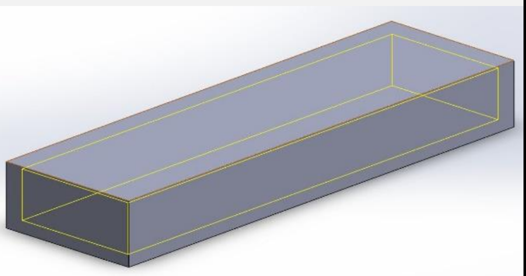
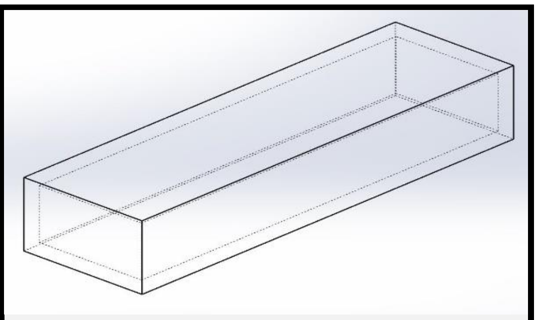
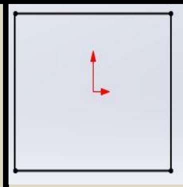
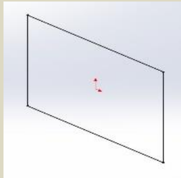
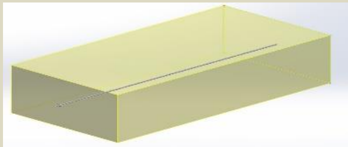
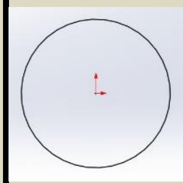
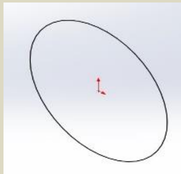
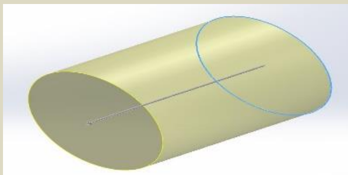
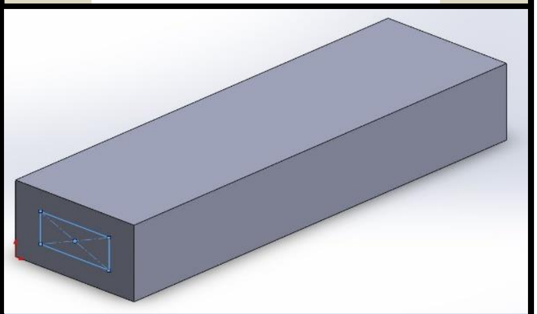
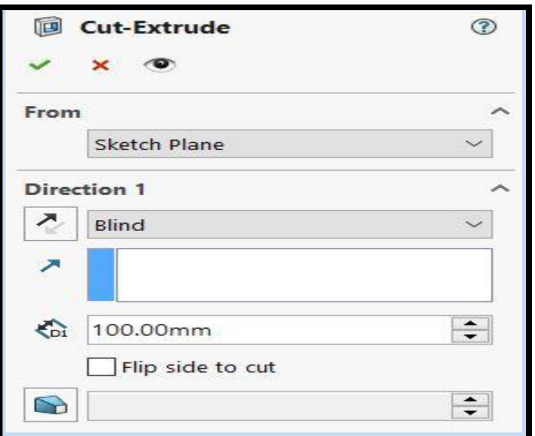
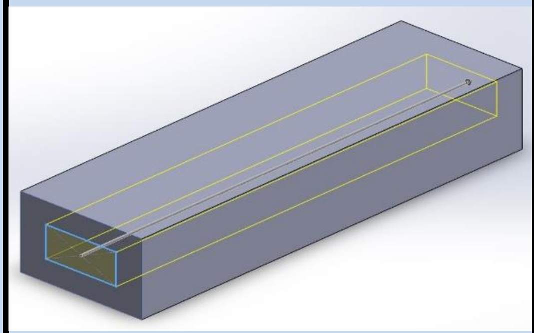
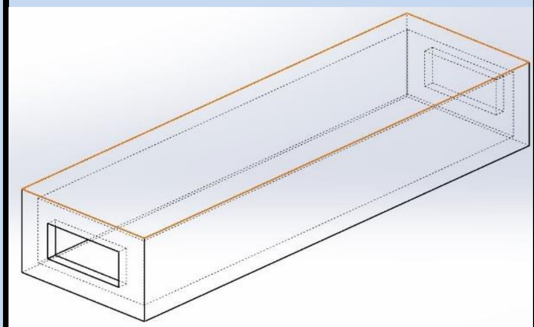
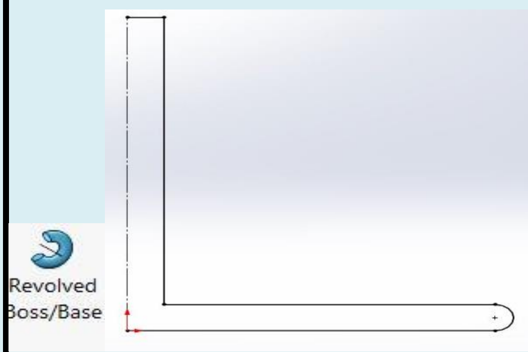
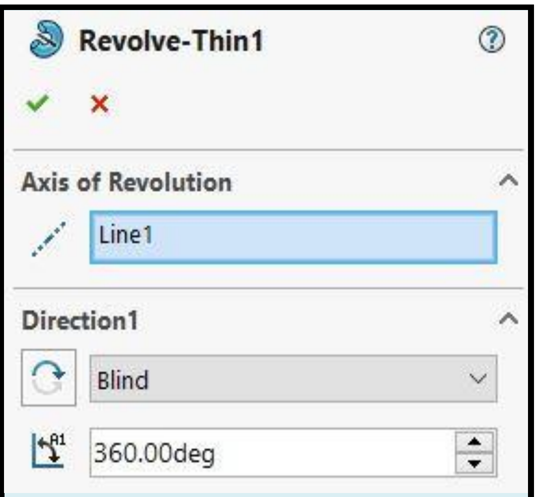
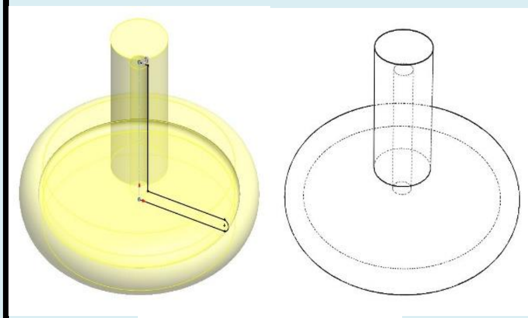
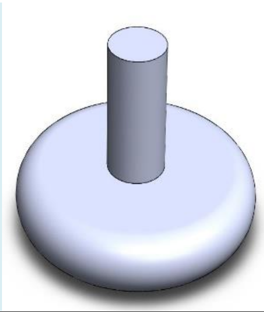
		

Table 3.2 Indicative 3d features

3D Feature	Definition/ Procedure	Command Deployment Illustration
Shell	It's the process of hollowing the part and it's not interrelated to a 2d sketch/The command is performed by choosing the desired shell thickness	 

		
Extrude Boss Base	It’s the process of converting a 2d sketch to 3d solid part/The command is performed by adding thickness to a 2d sketch	     
Extrude Cut	It’s the process of subtracting unwanted portion of solid from the part and a 2d sketch is required for the command performance	 

		  
Revolve Boss Base	It's the process of creating a 3d part deriving though by a 2d sketch/In order the command to be performed an axis of revolution is mandatory	

4. G-CODE SOFTWARE

4.1. Introduction to Preform

The software is an open source slicer which accepts STL files and converts them in bitmap set of individual layers (slicing).The conversion for slicing takes place through WebGL which converts the geometry in a series of coordinates something comprehensible for the printer. It can import *stl or *obj formats. When the software is installed and launched a pop up window appears enabling the user to choose the model of the printer (Fig 4.1) but also the material that will be used as shown at Fig 4.2.

Fig 4.1 Selection of the cooperative printer
Ref. Screenshot taken by Preform+1

Fig 4.2 Selection of the construction material
Ref. Screenshot taken by Preform+1

Furthermore, by the setup Tab the layer thickness can be specified by a slider bar as depicted at Fig 4.3.

Fig 4.3 Layer Thickness
Ref. Screenshot taken by Preform+1

By moving the slider at the left the print mode turns to be more fast (0.1mm) while the right side of the bar results at good resolution during printing (0.025mm). For the coin and mould construction, a layer thickness of 0.1 mm will be used, the same layer thickness that will be used for the FDM coin and dies. The printer is set to be Formlab +1 and the construction material will be white resin. The software provides a view menu icon for zoom in or out by use of the “+”- “-“button and for rotation control by 90° to the right, left, bottom and top as shown at Fig 4.4.The software is equipped with a main tool bar as shown at Fig 4.5, by which the model can be resized, reoriented and furthermore provides the ability of edit supports either automatically or even manually.

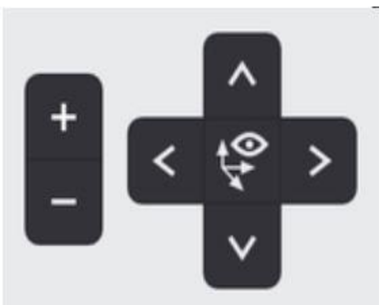


Fig 4.4 View Icon
Ref. Screenshot taken by Preform+1 Manual

A significant feature for SL processes is the need for supports which is mandatory especially for parts with intricate geometry.

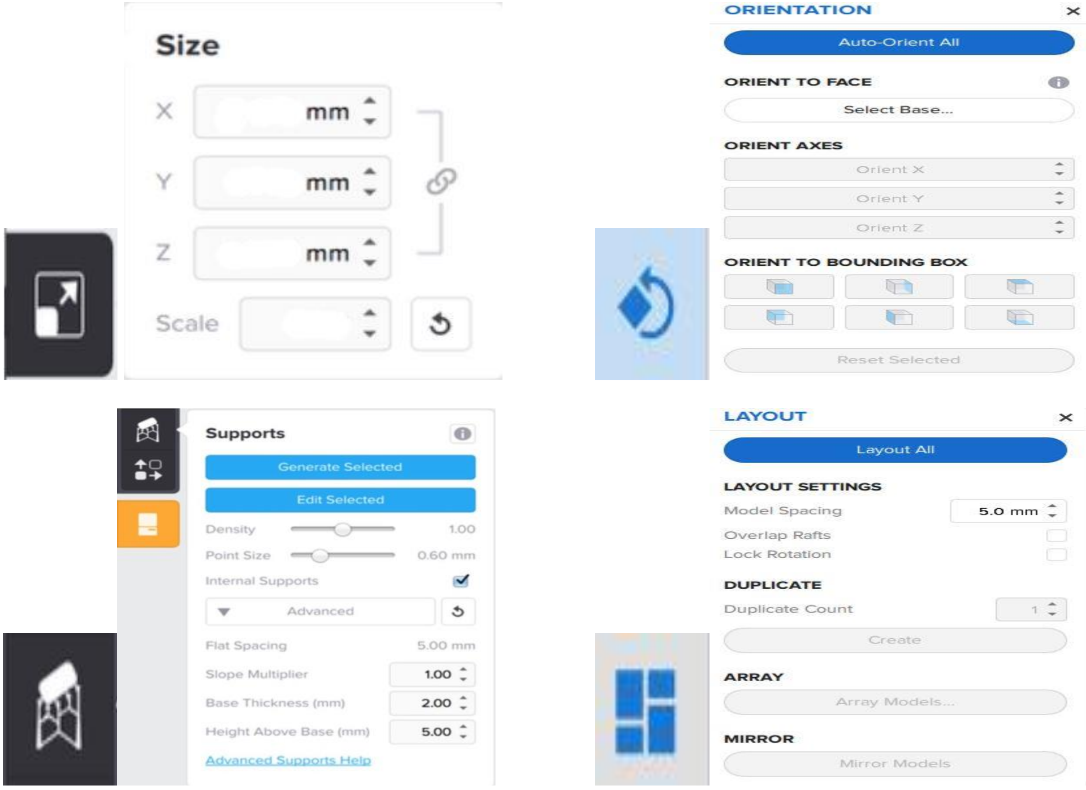


Fig 4.5 Main Toolbar
Ref. Screenshot taken by Preform+1

As shown at Fig 4.5 the software provides two sliders which refer to the density of the created support, and the size of the point to be set as support. Additionally, the software provides the ability of use internal supports by enabling it by the check box. Below, the three parts will be imported and manipulated mostly focusing on supports emplacement which is mandatory for the parts to be built.

4.2. Introduction to Ultimaker Cura 4.4

Ulitimaker Cura 4.4 is a free download software version used for creating g code for an object to be 3d printed. In this chapter a theoretical presentation of the software interface and settings will take place and subsequently the procedure of settings modification at factors which have impact on built time and print quality regarding the construction of the coin and moulds will follow.

4.2.1. General preface settings

When the software is installed and activated a preview of the built platform as shown at Fig 4.6 and an incorporated window with the settings (Fig 4.7) will pop up.

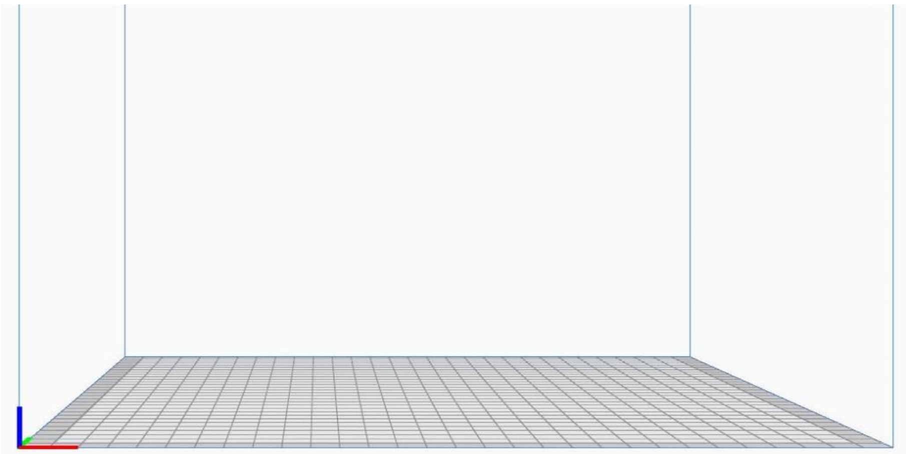


Fig 4.6 Built Platform
Ref. Screenshot taken by Ultimaker Cura 4.4

Fig 4.7 Settings window
Ref. Screenshot taken by Ultimaker Cura 4.4

First, the software must be connected with the printer to be utilized. For that the settings tab at the main toolbar is used with the procedure of printer enablement shown at Fig 4.8. When the printer is connected and activated by settings configuration the software enables the user to interfere to the structure by the deployed commands under main settings tabs (Fig 4.9).

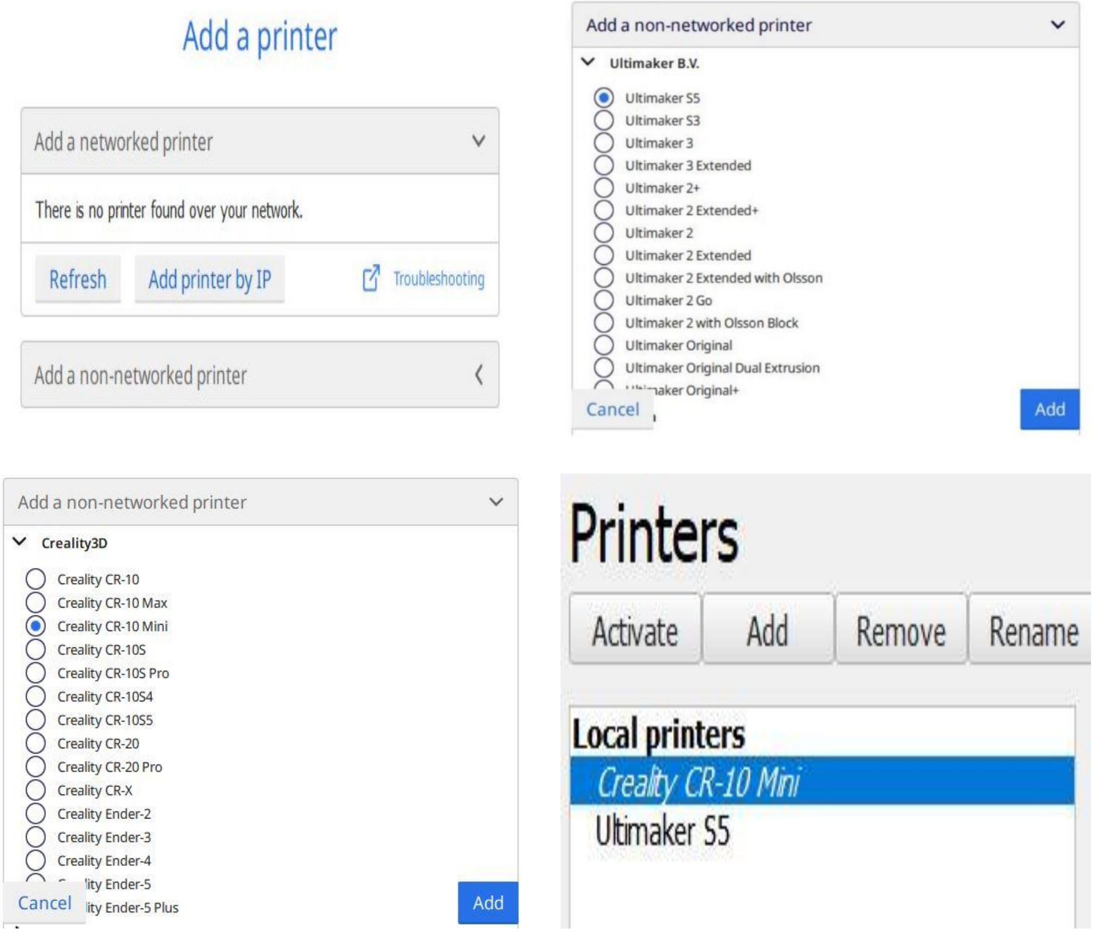


Fig 4.8 Selection process of 3d Printer
Ref. Screenshot taken by Ultimaker Cura 4.4

The software gives the ability of manipulating for instance print quality for compensating built time when a feasible object for presentation purpose (ex. a prototype) is required whilst it enables the user to choose if he is willing to sacrifice built time for obtaining a delicate and detailed final product by focusing on factors, such as print speed, infill density. At next sub chapter the deployed commands will be presented for comprehension of the software principles.

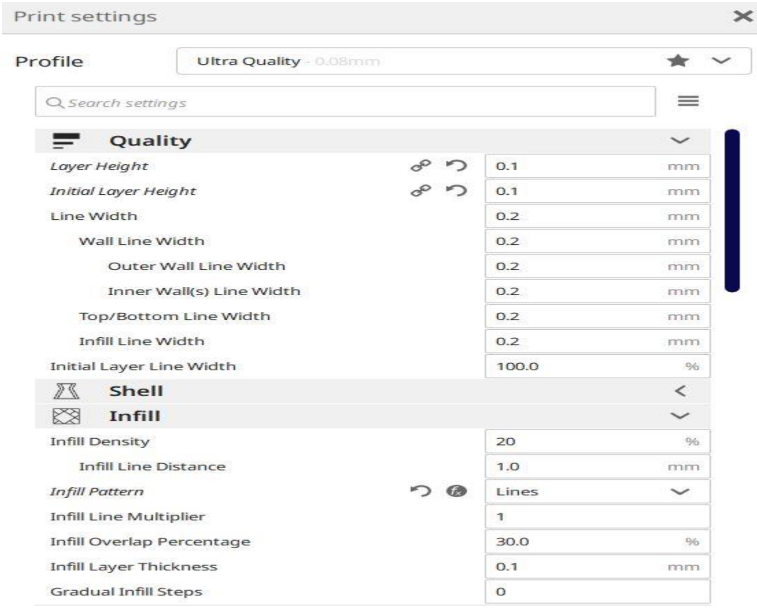


Fig 4.9 Main print settings
Ref. Screenshot taken by Ultimaker Cura 4.4

4.2.2. Explanation of preface tabs

Quality Tab

Layer height gives the ability of controlling the layer height which results in very good resolution but with bad impact on built time

Shell Tab

Shell settings are closely related to the outside structure of the print

. Wall Thickness adjusts the thickness of outside walls influencing the structure of the model regarding x-y axis. This value divided by the wall line width results to the number of walls and is generally a multiple of the line width. For instance when using a wall line width of 0.3 mm, it is rational the wall thickness to be set at 0.9 mm (3 * 0.3), which means that the outer structure of the print will consist of 3 walls. Wall thickness of 2 or 3 times the line width is sufficient.

Wall line count defines the number of walls to be printed and derives by the division of the layer width and wall thickness

With Top/Bottom Thickness the thickness of the top and bottom layer is defined.

Top Thickness determines the thickness of the top layer at the print

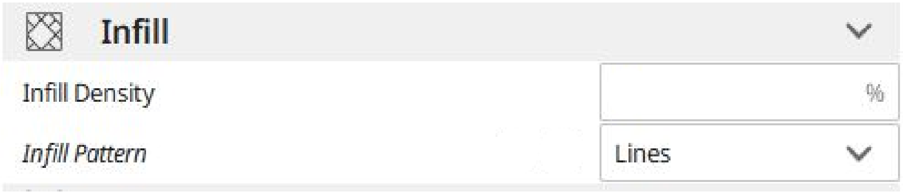
With this option the number of layers regarding the structure of the top layer can be defined. It derives by the division of the top layer to the layer height. For instance, if the layer height is set to be at 0.12 mm under Profile Tab and the top thickness is set to be 0.84 mm the number of layers that derive are 7

Bottom Thickness defines the thickness of the bottom layer at the print

With this option just as the top layers setting the number of layers regarding the structure of the bottom layer can be defined. It derives by the division of the bottom layer thickness to the layer height. For instance, if the layer height is set to be at 0.12 mm under Profile Tab and the bottom thickness is set to be 0.84 mm the number of layers that derive are 7

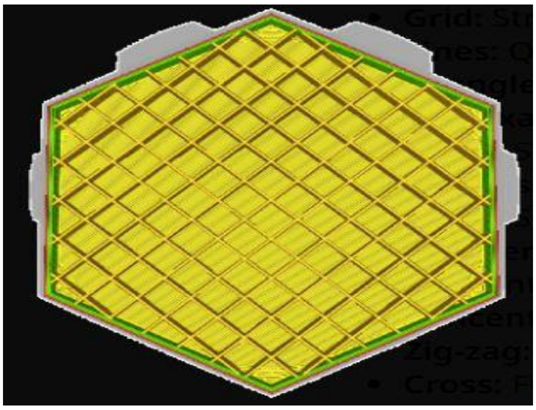
Horizontal Expansion option

Infill Tab

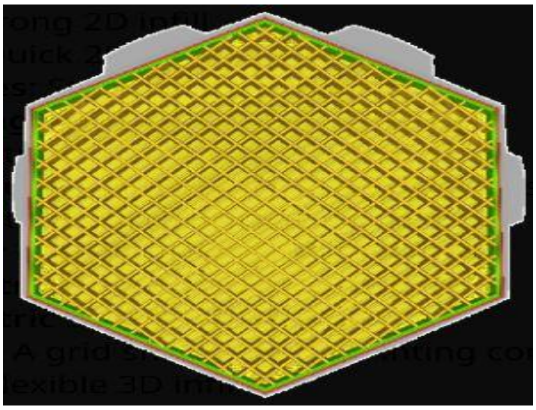


This setting controls the infill structure of the part. For a total solid part the value must be set to 100% whilst for an empty part at 0%.This has a strong impact regarding part's mechanical properties

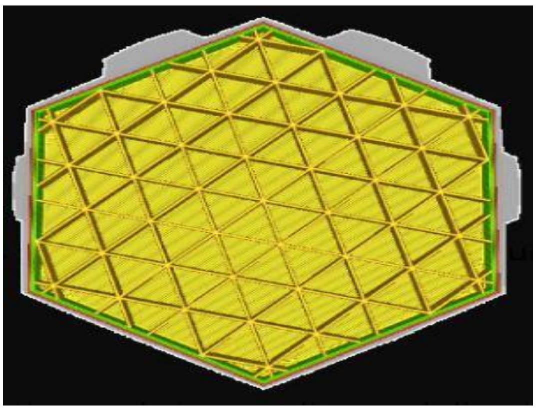
Infill pattern controls the way that the infill print will be structured using variable option. At the Figures below various infill patterns offered are presented

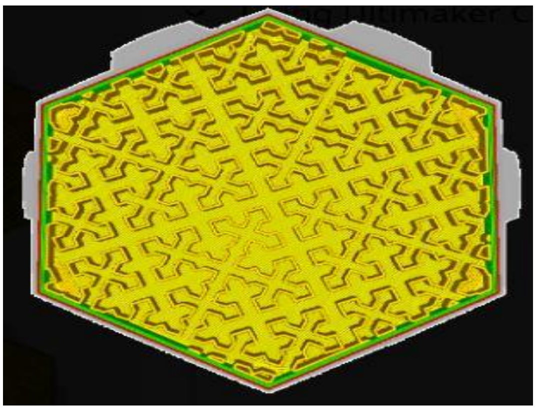


Cubic Pattern provides strong 3D Infill



Line Pattern is used for quick 2D Infill

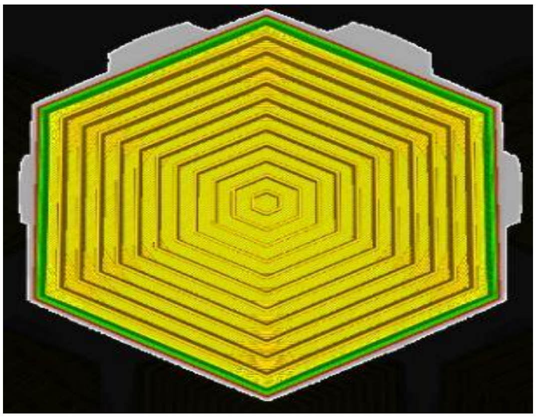


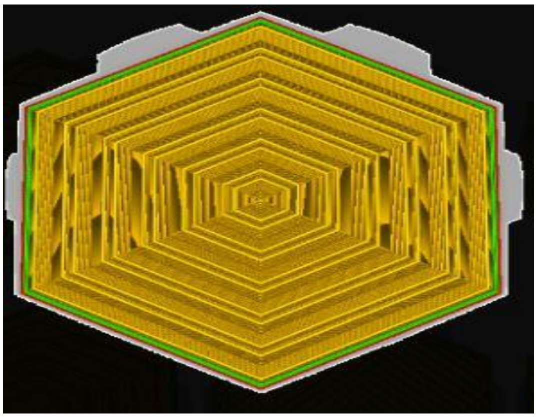


Tri-Hexagon provides strong 2D Infill

Cross pattern is used for flexible 3D Infill

\





Concentric Pattern is used for flexible 3D Infill structure

Concentric 3D Infill is used for 3D Infill structure which will be quite flexible

Screenshots taken by Ultimaker Cura Web Site
https://ultimaker.com/en/resources/52670-infill

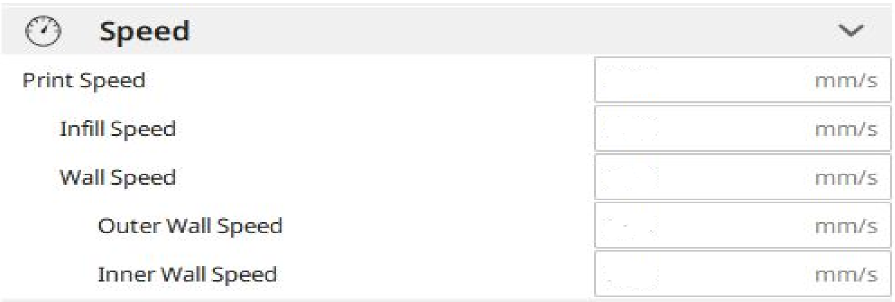
Material Tab

This setting defines the temperature of printing meaning the temperature at which the material will be deposited

By this setting the temperature of the built platform can be modified

Retraction is used for not wasting material during the travel movement between two printed parts .This means that the filament is pulled back by the feeder, so that it doesn’t leak from the nozzle. By using retraction, the appearance of thin threads of plastic in between the printed parts is prevented, resulting in a much cleaner final model.

Speed Tab



This setting depicts the speed of printing. Some proficient AM machines has the ability of printing at a speed up to 150mm/sec without sacrificing printing quality

This settings defines the speed at which the infill structure will happen

Wall speed defines the speed at which the structure of the wall will happen

Outer wall speed modifies the speed at which the outer wall of the part will be printed

Inner wall speed determines the speed at which the inner walls will be printed

Travel Tab

5. ADDITIVE MANUFACTURING

Additive Manufacturing can be mentioned also as 3d Printing technology. Although 2d dimensional inkjet printing devices were commercialized for printing images and documents from a computer or other devices since the 1960s 3d printing technology was inducted at the ‘80s with the development of ballistic particle manufacturing which utilized the use of deposition material upon material in particle form. The first successful 3d Printing device came in 1994 by Sanders Prototypes and involved 3d printing a part with wax as construction material the Modelmaker. In this chapter a presentation of processes, development stages and utilization of Additive Manufacturing processes will follow.

5.1. What is Additive Manufacturing?

Rapid Prototyping (RP) is the process for the creation of a product and its physical representation before this is ready to be launched to the market. Basically, is the process of creating a prototype very fast and by which the final product will derive. The basic aim of this technology is that a model which was first designed with use of CAD, can be constructed without the need of plan regarding the process sequence. Other manufacturing principles set requirements regarding a detailed analysis of the part’s geometry, like tools and processes that should be used etc. On the other hand, AM processes require some basic details regarding dimensions and comprehension of material use and how the machine works. The key feature for AM processes is material deposition in form of layers. The CAD data provide information to the Additive Manufacturing machine regarding the structure of every layer. The delicacy of the outcome is strongly depended on each layer thickness, meaning that thinner layers result in a better outcome. Although all of the AM machines in the market make use of the same principle for fabricating a part, the layer by layer process, they differ in some other aspects, such as, the way layers are constructed or the bonding of each layer with the previous one. Those factors play a crucial role regarding fabrication time, post processing methods that are required or even have a strong affect at the total cost of the processes and machines.

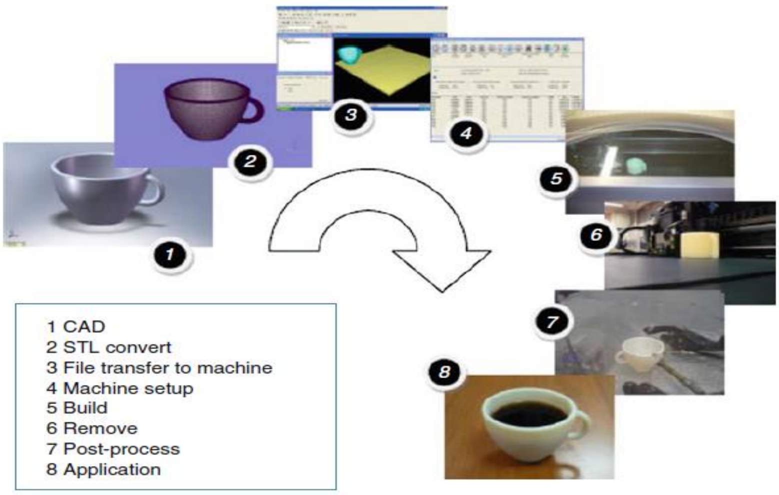


Fig. 5.1 Fabrication of a part, starting from a CAD model and going through eight stages until the final product
Ref.: Additive Manufacturing Technologies
Rapid Prototyping to Direct Digital Manufacturing
I. Gibson l D. W. Rosen l B. Stucker

5.2. Additive Manufacturing as generic process

Additive Manufacturing involves a sequence of actions for the production of the final part, starting from the virtual design of the product in Computer Aided Design (CAD) software to the resulting tangible product. Some products require different manufacturing processes, for example, an intricate product requires the use of AM multiple times in several stages of the development process. Due to the fact that at the early stages of the product development rough models are required for the

5.3. The eight principles of Additive Manufacturing (AM) processes

The cascade of actions in Additive Manufacturing (AM) is quite similar to all AM technologies but with slight variables according to the design and the appropriate production technique required.

Step1: Conceptualization and CAD Reverse Engineering

The initial stage in development process of a product is the ability of inventing new ideas regarding product’s appearance and functionality. Conceptualization can differ from conceptual sketches to small descriptive models. Due to the fact that products with intricate features require multiple stages for its production a CAD model description is required, which shows the strong interrelation between AM and CAD principles. In general, all AM processes can be defined as the transition of Computer Aided Design (CAD) models to Computer Aided Manufacturing(CAM).The majority of AM systems are solid systems which are sometimes constructed with surface combination. Consequently, almost any CAD model can be constructed by the use of AM processes.

Step 2: Conversion to STL files

The use of *stl format as a term STL came up by the initials of STereoLithography technology. The idea of *stl format apply the use of triangular facets for approximation of the surfaces together. The size of those facets is the distance between the plane of the triangle in conjunction with the surface that they should represent. The conversion from CAD format to STL is an automatic process and involves an error probability which is resolved by incorporated software able to detect and repair those errors. Intricate surfaces may result in problems regarding their alignment, thus, the creation of gaps. Therefore, some software offer the ability of merging-bridging the gaps in a way that automatically smoothly substitutes them or enables the user to interfere manually

Step 3: STL files manipulation

When the STL file is ready it can be transferred to an AM machine. Before that, some preliminary actions should be taken into consideration though before the final transfer to the AM machine. Most of the AM software provide the additional tools regarding the illustration of the built up procedure of the product, and enable the user to manipulate the object by will. With help of illustration the object can be repositioned or reoriented by the user in a way that fits the whole built up platform. Furthermore, some manipulating tools give the ability of slicing the part to smaller ones produced regarding spatial matters.

Step 4: Setup specifications

The majority of AM devices make use of variable materials while some few exploit the use of only one or two for the construction of a 3D object. The settings differ between different AM machines and enable the user to trial various settings in order to find the right built up balance depended on the aim that has for the part. For instance, a designer may want a prototype very soon for presentation purposes which means that he’ll be more concerned about the lack of time instead of caring about the printing quality. In this case, the modifications should be done accordingly due to the fact that time and printing quality in Additive Manufacturing are two strongly interrelated notions.

Step 5: Structure of the part

All of the AM machines follow the same principle regarding layer and control of deposition using an adjustable platform at height and formulation of layer's cross section. A difference between some AM machines is that some of them use a simultaneous deposition and formation of material while others separate them. The layer deposition and formation procedure will repeat itself until the full construction of the product.

Step 6: Remove-Cleaning the part

At this stage the part is ready whilst needs some finishing in order to be considered finished. The part either should be detached from the platform in which it was built or the excessive material used as built supports should be removed. Constructed AM parts may require different post processing methods but in this phase cleaning is a common action for all of them.

Step 7: Post processing actions

This step involves part's finishing for its eventual purpose. Finishing consists of polish and sand papering or even coating. Built up speed is a crucial factor regarding the amount of post processing methods required, meaning that the precision and surface finish treatment for an object built with high speed differs by one which was built with lower printing speed.

Step 8: Utilization

All parts at this phase are considered as full functional and ready for use. Some AM processes tend to produce parts of lower mechanical strength due to the creation of voids or bubbles in the structure something that could lead to a potential mechanical failure. Furthermore, some AM processes result in material degradation (non bonded or non crystallized optimally layers) making the structure susceptible to mechanical failure

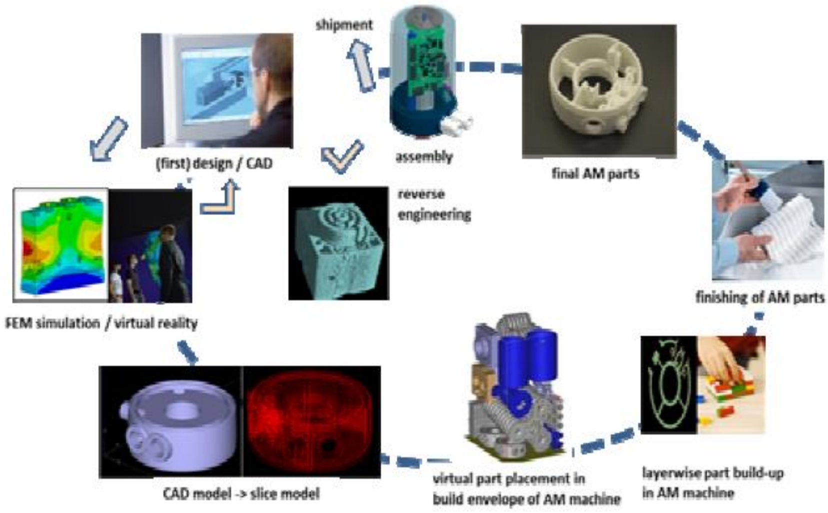


Fig 5.2 Additive Manufacturing as part of a solution process
Ref.: Additive Manufacturing as Integral Part of the Digital Solution Process - An Industrial Short Note
Klaus Müller-Lohmeier
Festo AG&Co. KG, Esslingen, Germany

5.4. Benefits of Additive Manufacturing (AM)

A crucial characteristic of additive manufacturing has to do with speed. The advantage of speed doesn't rely only on the construction time of the parts. The whole development process speeds up due to the fact that there that there is no need for someone to understand and interpret the design intent since a CAD software is used from the start and is rather simple to be transferred to AM machines. Another significant fact is that no matter how complex a part can be, for an Additive Manufacturing machine is done in just a single step compared to other manufacturing methods that might require multiple iterations for the final outcome. Furthermore, the number of required processes can be dramatically declined with the use of AM machines .For instance, a craftsman would divide the structure of a prototype into multiple stages because the prototype would be subjected to various construction methods.

5.5. Stereolithography (SL) process overview

SL process is utilized for the creation of 3D solid or hollow parts by solidifying liquid photopolymer resin with a laser accounted for that. The procedure takes place by fabricating an object in layer by layer deposition of 2d sectional contours, one upon the other. The laser identifies the contour by help of a CAD model and selectively solidifies the particular area so that each layer to be created. The process repeats itself until the last layer is constructed.

5.5.1. Photopolymerization

Photopolymerization makes use of radiation curable resins as the standard material. The majority of photopolymers are sensitive to radiation from UV light. During irradiation these photopolymer resins are subjected to a chemical reaction for their transformation to solid objects. The first investigation took place regarding photopolymers started at the late ‘60s and they were soon inducted in the industry especially in coating and printing sector. In the middle ‘80s Charles Hull, did some experimentation regarding UV curable materials adopting the principles of laser printers meaning that the material is subjected to laser scanning. He came to the conclusion that a 3D solid polymer part could be fabricated using the layer upon layer principle. Essentially, this was the advent of STereoLithography as technology. The term “vat Photopolymerization” is used for the combination of Stereolithography and the related processes for the fabrication of a 3D object.

5.5.2. Irradiance and exposure

During laser scanning a line of resin is cured but the depth of curement is related to various factors. The shape of the line cured is interrelated to resin characteristics, laser energy attributes and scan speed .Irradiance is the radiant power of the laser per unit area. During built procedure the Z axis is considered to be perpendicular to the resin vat, thus in its surface also, and the origin at “p” point has as coordinate x=0.The irradiance at any point of the coordinates x, y, z is interrelated with the irradiance at the resin surface.

5.5.3. Laser scan vat Photopolymerization process

The process involves the fabrication of a 3D part with solidification of selectively photopolymer resin in fluid state with use of UV laser as shown at Fig.**1**. Not differentiated from the other Additive Manufacturing processes it makes use of cross sectional contours for constructing an object with layer upon layer fabrication. The platform of the printer is dipped in a vat full of resin.

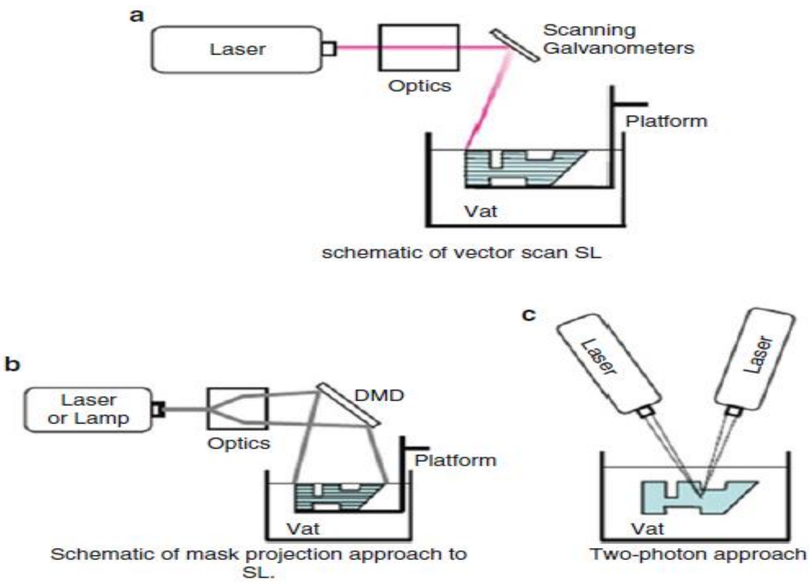


Fig 5.3 Schematic approach of three vat polymerization methods
Ref.: I. Gibson et al., Additive Manufacturing Technologies,
DOI 10.1007/978-1-4939-2113-3_4

When every layer is fabricated the platform lowers and the vat surface is recoated. At this point the laser starts to identify the next layer track by the help of CAD model. For the construction of the part a sequence of actions must be held, such as , input data, part and layer preparation and eventually scanning of the cross sectional layers.

Input data: The input data has to do with the STL file of the object created by the CAD model or by the reverse engineering process

Part preparation: Involves the specification of support structures needed, for ensuring that the fabricated part will stay in place during the structure of each cross sectional layer

Scanning: Scanning process is the phase that actually combines all of the previous sub stages and creates the object by solidifying each layer with use of a UV laser

When the construction is over some post processing methods should be applied, such as, post curement and cleaning processes as well as finishing processes. For cleaning, the support structures should be trimmed away and finishing includes sanding and polishing the surfaces for good surface quality.

5.5.4. Benefits and flaws of Vat Photopolymerization

Vat Photopolymerization has two crucial advantages compared to other AM technologies and these are accuracy, and part's finish. These pros led to vast use of vector scan stereolithography. The accuracy for SL machines is expressed as an error per length ratio. The surface finish of stereolithography parts varies between submicron Ra to over 100μm Ra. Another significant attribute of vat Photopolymerization is their flexibility. Several light sources are available such as, lasers, lamps or even LEDs. The size scale has an enormous spectrum from 1.5m vat to 100nm with two photon photopolymerization

5.5.5. Form 1+

Form +1 represents the SLA print technology ανδ τηε 3δ πριντερ in IHU premises. The generated model can have dimensions of up to 125 × 125 × 165 mm. It supports multiple resins each of which is suitable for a different purpose. FormLabs provides solutions for engineering purposes in which the solidified resin can either be tough or flexible or endure high temperatures, for dental surgery purposes where the solidified resin can be used as a surgical guide, for casting purposes where the solidified resin burns out cleanly without ash or residue and captures crisp, precise details and smooth surfaces and for other designing purposes offering outstanding performance and nice finishing.

Fig 5.4 Form+1 SLA printer

5.6. Fused Deposition Modelling (FDM) process overview

FDM is the most widely used AM technology based on material extrusion that was developed by Stratasys back in the '90s.(Fig 5.5).

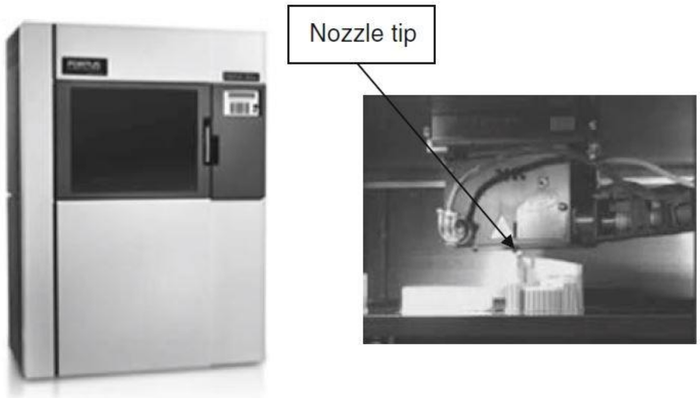


Fig 5.5 Typical Stratasys machine showing the outside and the extrusion head inside
Ref. Additive Manufacturing Technologies-Rapid Prototyping to Direct Digital Manufacturing
Gibson I D. W. Rosen I B. Stucker

This method uses a chamber that heats and liquefies polymer and then is fed into the system in liquid state by passing through a nozzle. The filament is stored in spool form and is guided in the translucent chamber by help of two rotated placed-opposite one to the other-gears that guide the filament into the chamber. This way the gear system produce pressure which if remains constant the filament will be coming out of the nozzle at liquid state and with specific diameter and rate. The diameter of the extruded filament will remain unchanged if the nozzle travel speed along the contours is kept intact something that results in a constant material flow rate. (Fig 5.6). When each layer is constructed the print head will have to go up at an equivalent height to the previous deposited one for the construction of the subsequent layer or the print head will stay at the same point while the built platform will lower at a height equivalent to the deposited previous one.

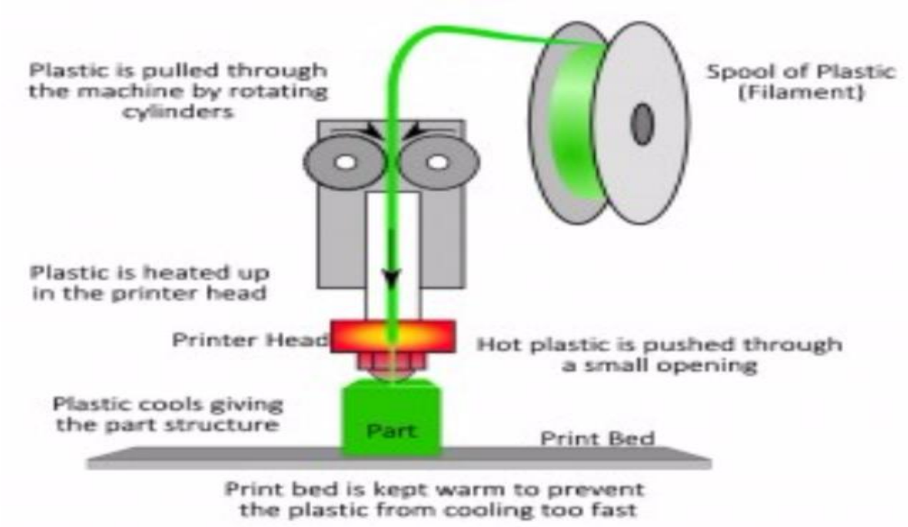


Fig 5.6 FDM process overview
Ref. Screenshot taken from Google
https://www.sd3d.com/fff-vs-sla-vs-sls/

5.6.1. Benefits and flaws of Fused Deposition Modelling

A crucial advantage of FDM process has to do with the vast variety of offered materials and the efficient mechanical properties of the produced parts.FDM are parts of increased toughness compared almost to any polymer based AM process. On the other hand a flaw regarding FDM process is the built speed which is significantly lower compared to other AM processes. Furthermore, if the print settings are not applied properly print quality can be significantly deteriorated as shown at Fig 5.7.

Fig 5.7 Defects of print quality
Ref. Screenshots taken by
https3dsourced.comguidesfused-deposition-modeling-FDM

5.6.2. Creality CR10 mini overview

Creality CR10 mini is a domestic 3d Printer used for the structure of the coin and moulds using FDM process (Fig 5.8).

Fig 5.8 Creality CR10 mini
Ref. Screenshot taken by Creality CR10 mini Manual
https://www.creality.com/

The device consists of the main unit (Fig 5.9) by which the printing and device parameters can be modified, the printing head which consists of the heating unit, a nozzle at the end of the printing head and a small fan attached upon the printing head for cooling down the heating unit during printing process as shown at Fig 5.10.The filaments compatible to CR10 mini are ABS, PLA, PET. For the coin and moulds PLA will be the chosen material for construction. The filament comes in spool form (Fig 5.11) and is guided to the printing head and eventually to the nozzle through a tsanslucent tube. Depending on the construction, material used, printing quality or the construction time by the device interface at the main unit the settings can be set up accordingly (Fig 5.12).

Fig 5.9 The main Unit of CR10-mini Fig 5.10 The Printing Head with incorporated fan
Ref. Screenshots taken by Creality CR10 mini Manual
https://www.creality.com/

The connection of the device with the slicing software is done by an SD card which is inserted in the main unit slot and enables the device to obtain the gcode for the printing process (Fig 5.13).

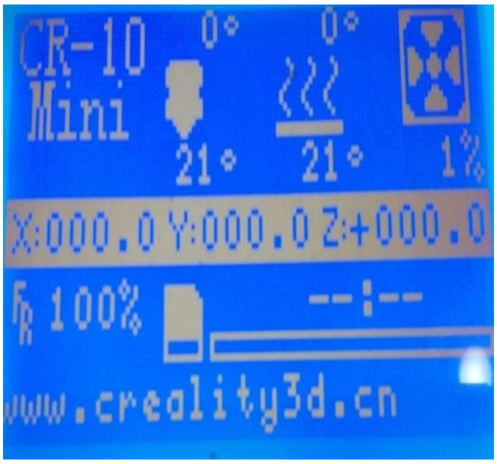


Fig 5.11 Filament in spool form Fig 5.12 CR10 mini Interface
Ref. Screenshots taken by Creality CR10 mini Manual and domestic CR10 mini Interface
https://www.creality.com/

Before printing takes place as mentioned above some preliminary actions should be applied.

Bed leveling: The bed platform should be flat during printing process so that probable defects due to bad leveling to be avoided as shown at Fig.5.14.The device should first return to the platform’s origin which is the bottom left corner of the bed by operating the “Autohome” command (**Fig.5.15**) and then the x, y, z steppers should be disabled so that the printing head can be moved manually (**Fig.5.16**).A piece of paper will be used as measure of the gap between the bed and the nozzle of the device. The right leveling happens when the friction is just as much as the nozzle will slightly scratch the paper. For the leveling process four identical rotating knobs are placed at the bottom surface of the bed dispersed at the four corners.(Fig.**5.17**).

Fig 5.13 Insert SD card for gcode transfer to the device
Ref. Screenshot taken by Creality CR10 mini Manual
https://www.creality.com/

With the platform leveled the printing head should return to the origin which is the bottom left corner. This will be done by using Autohome command again.

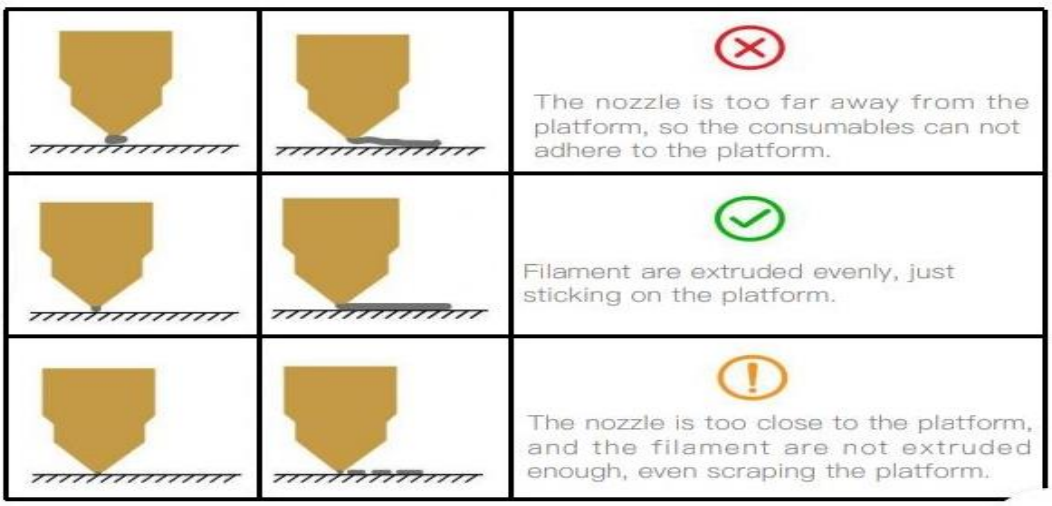


Fig 5.14 Defects due to bad leveling
Ref. Screenshot taken by Creality CR10 mini Manual
https://www.creality.com/

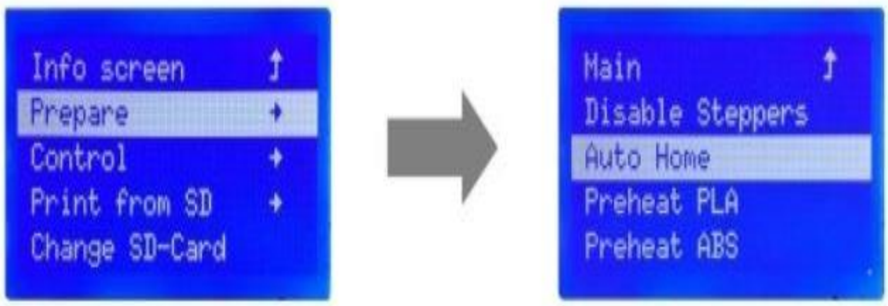


Fig 5.15 Autohome command

Ref. Screenshot taken by domestic CR10 mini

The next step is the filament to be fed to the printing head as shown at Fig.5.18. The filament has to be guided manually in the tube by pushing by one hand the knob adjusted on the start of the tube and by the other hand pushing the filament into the tube until the point it stops going further. During operation the material is guided through the plastic translucent tube to the nozzle automatically by the help of two opposite placed gears which by rotation actually “suck” the filament into the tube.

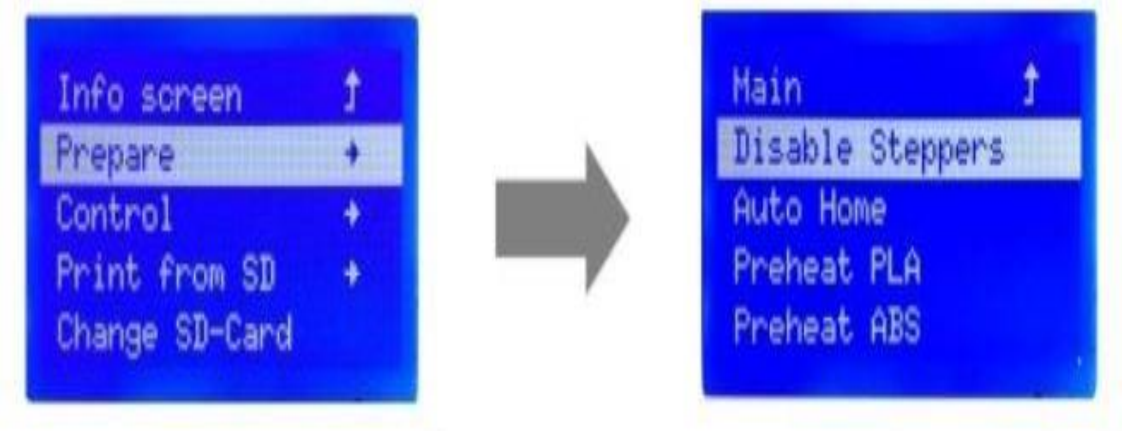


Fig 5.16 Disable Steppers command
Ref. Screenshots taken by domestic CR10 mini

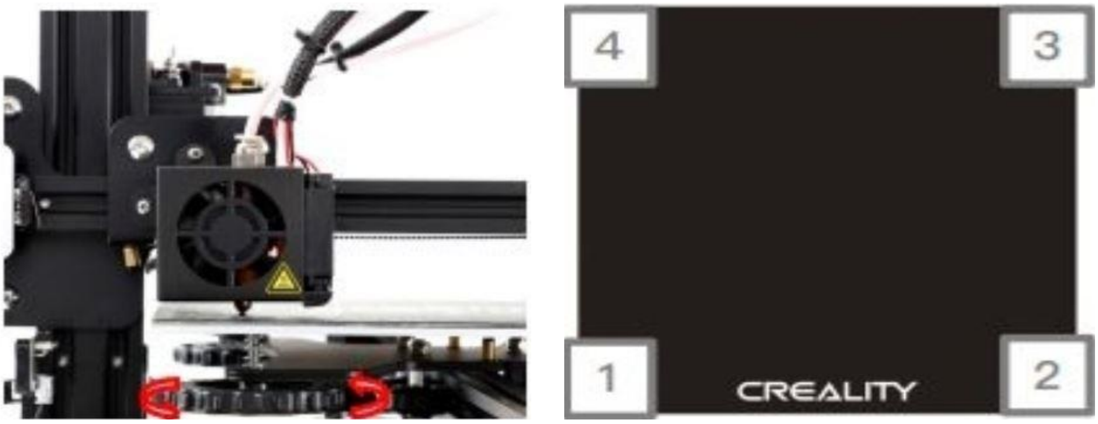


Fig 5.17 Bed leveling process
Ref. Screenshot taken by Creality CR10 mini Manual
https://www.creality.com/

Fig 5.18 Guiding the filament in the printing head
Ref. https://www.creality.com/

With the filament loaded the device is ready to perform. For performing printing the material should be preheated. This can be done either automatically by the device itself either by manual set up of the printing parameters a shown at Fig. 5.19 and Fig.5.20.

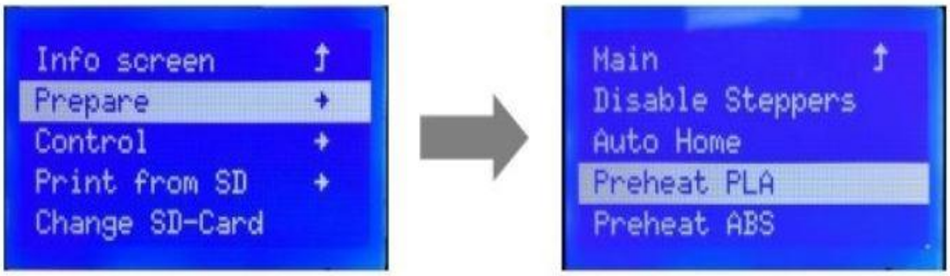


Fig 5.19 Automatic preheat
https://www.creality.com/

Fig.5.20 Manual temperature specification
Ref. Screenshots taken by domestic CR10 mini

Before selecting the desired gcode for printing with the bed already preheated a layer of glue as adhesive component will be applied at the platform area within which the parts will be constructed as shown at Fig.5.21.

Fig 5.21 Glue application for better adhesion
Ref. Screenshot taken by Google

When the temperatures reach the desired limits the printing process can begin. By the user interface and the option “Print from SD” the desired gcode is chosen and at that time the temperatures of the platform and the nozzle will adjust to the specifications applied at the slicing software (Fig.5.22).

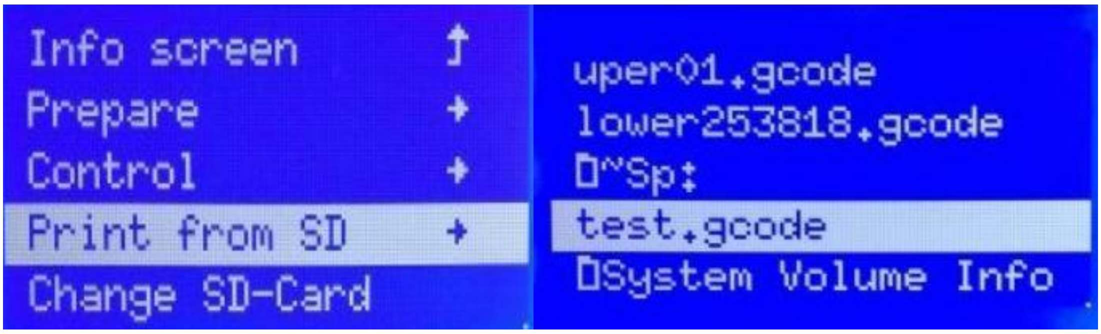


Fig 5.22 Print Command
Ref. Screenshot taken by Creality CR10 mini Manual
https://www.creality.com/

5.7. Differences between FDM and SLA process

Fused Deposition Modeling (FDM) and StereoLithography Apparatus (SLA) are two Additive Manufacturing processes which utilize the same principle for fabricating an object, the layer by layer structure. These two processes though have some significant differences regarding the construction material, the adhesion and the detachment from the built platform etc which are presented at Table 5.2

Table 5.2 FDM-SLA comparison

	Additive Manufacturing Process	
	FDM	**SLA**
Material	PLA-PETG ABS-Nylon-PVA-TPU	Resins
Color	various colors	blue, black White, grey, clear resins
Precision and Smoothness	Resolution relies mostly on nozzle size and other factors, precision encounters warping, shrinkage due to bonding force or the weight of the upper layers	Higher resolution due to the fact that resolution is related to the spot size of the laser. Due to lower forces applied during construction the surface finish is much smoother
Adhesion-Detachment on the	It's a relatively easy procedure and it can be handled with use of a palette knife	It's much more difficult to detach the part from the print

built platform		platform and there are more residuals left
Supports	The presence of supports isn't mandatory but if they are applied they can be easily removed	The presence of supports is obligatory. The residual resin is removed by isopropyl alcohol bath

6. TRADITIONAL MANUFACTURING AND COINAGE

In this chapter the technique of plaster moulding will be presented. Additionally, a presentation regarding ancient and modern coinage techniques will follow with a supplementary sub chapter which depicts the attempts by counterfeiters for misrepresentation of genuine ancient Greek and Roman coins.

6.1. Ancient coinage techniques

During first years of minting a remarkable variety of animal figures advanced in the minting workshops of minor Asia. The anatomical perfection by which those animal figures were engraved shouldn't amaze anyone, if we take into consideration the delicacy and the precision of those figures engraved on the Minoan and Mycenaean signets. The engravers have constructed two stamps, one for the back and one for the front view, since of course coins were inducted with illustration on both sides in about 550 BC. The history of coin production relies mainly on some artifacts found in several period of time but in general, Coins in Antiquity were constructed with forged process and were called "paista" or "petals". Initially the "petals" were made and by stamping they were transformed to coins, a truly stunning process. Every coin was made by hand in a careful prepared matrix in which metallic discs of equal diameter and weight were poured. Diameter and weight were significant factors for the value of a coin. The matrix was made out of bronze, brass or iron and was heated and prepared during it was still soft and after that it was hardened. A coin version for a large city or kingdom included minting hundreds or even million of coins. That's why the matrixes were crumbled during the production and were sent to the sculptor either for restoration or replacement. Sculptors made sure that the design would have the appropriate form in order to predict that during hitting the molten metal would be poured at the opposite matrix at every spot. The amorphous "petals" were heated in order to get softer and be easily imprinted. One of the engravers was heating the "virgin" coin and when it reached the right temperature by the help of a grasper put it on the anvil in which the front view was stuck while the back view was placed on the «χαράκτηρ» and one of the engravers was holding it with his hand. So, while one of the two engravers was holding the heated “petal” between the two dies (the anvil and the «χαράκτηρ») the other one was hitting the «χαράκτηρ» with a hammer several times. By this, the details of the dies were conveyed to the “petal” as shown at Fig. **6.1**.

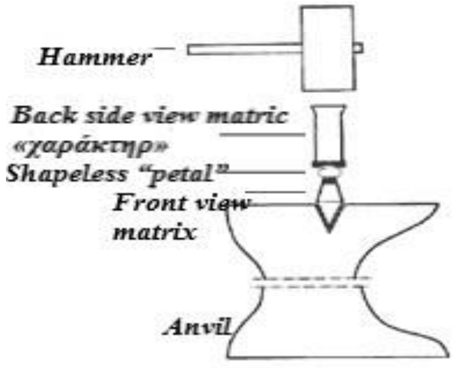


Fig 6.1 Coin engraving process in an ancient mint workshop
Ref. Screenshot taken by Google

An ancient Greek mint workshop consisted of a small erection which had a small furnace. The tools used for the coin construction were limited and consisted of a scale for weighing the metals that would be transformed to coins, a “graver” and a “stigma” for engraving. Initially, the metal before converted to coin had a “marble” shape. With the advance of technical methods the metal was cut with a hacksaw while it was in a rod shape.

6.2. Modern coinage techniques

Nowadays, the modern minting technique is accompanied by a high mechanical and aesthetic degree of excellence and superiority. This involves a logical cascade of defined procedures beginning with coin design. The design is made by an artist by use of a pencil sketch. Once the design is approved, the dies and moulds according to the design are prepared. The selected design in all its details is transferred onto a plastilene model, which is made up to five times the size of the actual coin. This painstaking task takes about 3 weeks to complete and then the design on the plaster is then transferred onto a rubber resin mould which is later used to make an epoxy resin mould. Melted rubber is then poured into the 'Plaster of Paris' mould to form the

'Silicone Rubber'. The design on plaster gives a better finish than other materials used and any probable errors made can be corrected at this stage with plaster (Fig.6.2)

Fig 6.2 Manipulation of plaster mould
Ref. Screenshot taken by
https://www.fleur-de-coin.com/articles/modern-minting

Next, this epoxy mould is mounted onto a reducing machine called pantograph which traces the exact contour of the mould onto an engraved master die bearing the same diameter as the coin to be struck as shown at Fig.6.3.

Fig 6.3 Use of pantograph for engraving the coin's details upon the die
Ref. Screenshot taken by
https://www.fleur-de-coin.com/articles/modern-minting

From this master die, another working master die or master punch is made using a matrix die. The araldite mould is imported into a reducing machine, with the design traced on tool steel (Reduction Punch process) as depicted at Fig.6.4.

Fig 6.4 Reduction Punch Process
Ref. Screenshot taken by
https://www.fleur-de-coin.com/articles/modern-minting

The reduction punch will go through a few cycles until the master die is formed (Fig.6.5).

Fig 6.5 Master Die formation
Ref. Screenshot taken by
https://www.fleur-de-coin.com/articles/modern-minting

6.3. Coin Forgery

The use of stamps or names upon a coin was a method used for the certification of quality. As known, profit is strongly interrelated to human nature, so from the very beginning of coinage in ancient world several attempts of coin forgery took place either by silver coated versions of coins or by circulating coins of inadequate weight or even by placing a copper core into the coin. So, it's not uncommon to find an ancient banker's mark or a test cut in ancient coins. Sometimes, the sculptors of a mint workshop were using already published coins of other cities the so called «επικεκομμένα» .Regarding coin forgery many cities in minor Asia but also in the metropolitan Greece legislated especially strict laws. For example, in Mytilene, Fokaia and Athens the most probable verdict for a coin forger was the death penalty. Through centuries modern counterfeiters utilized manufacturing processes for replicating ancient Greek or Roman coins with their main purpose to sell them as genuine ancient coins in legitimate auctions or not around the world, such as sand casting.

Sand casted coins: The use of sand casting for coins derives from Sui Dynasty in 6th Century AD in china, a process which wasn't familiar to the Mediterranean region. From that time and until 19th century the majority of coins in china were made by sand casting process. For the Greek ancient coins several attempts of replicating coins with sand casting process were made. The mould for sand casting consists of sand mixed with binding agents upon which the surfaces of the coin is impressed and a spacer is placed upon it which will be used for separating the two halves. Upon the spacer the upper part of the mould is impressed. With the coin's details imprinted on the two halves the two parts of the mould are separated. The molten metal inflow is facilitated by a sprue which is created and additionally some air lines are created which will allow the air of escaping during pouring. The defects of sand casting process for some are more than obvious as shown at Fig.6.6 -6.7 and Fig.6.8.

Fig 6.6 Creation of ridges on the coin's circumference
Ref. Screenshots taken by Galgary Coin
http://www.calgarycoin.com/index.html

Fig 6.7 The texture of sand grains appears in a fake's coin surface with sand cast (front view of Balbinus Sestertius coin the genuine front view at the left and the front view after sand casted)
Ref. Screenshots taken by google and Galgary Coin
http://www.calgarycoin.com/index.html

Fig 6.8 Depiction of misrepresentation of Great Alexander’s silver Tetradrachm with sand cast process
Ref. Screenshots taken by google and Galgary Coin_
http://www.calgarycoin.com/index.html

At Fig.6.8 the image of those five coins together clearly shows that all the of the five coins are identical enough to be considered as genuine , yet many of the finer details are different due to the fact that the mold picks up slightly different details each time the master is impressed.

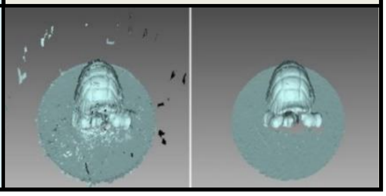
7. DEVIATION ANALYSIS WITH ARTEC 11 PROFESSIONAL

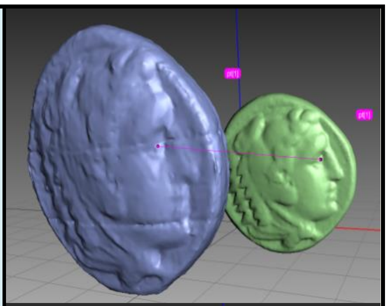
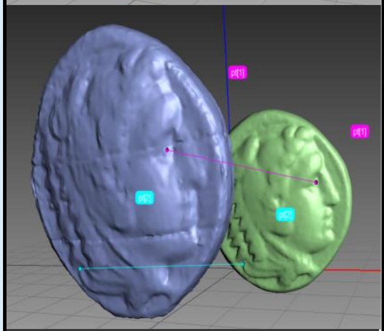
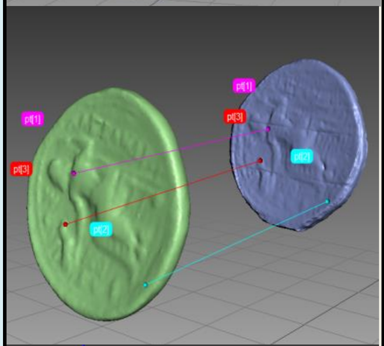
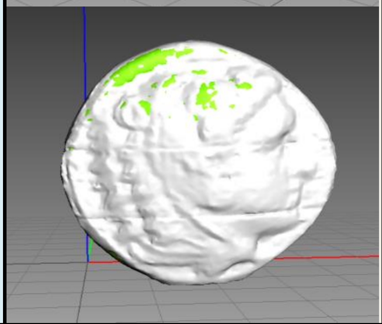
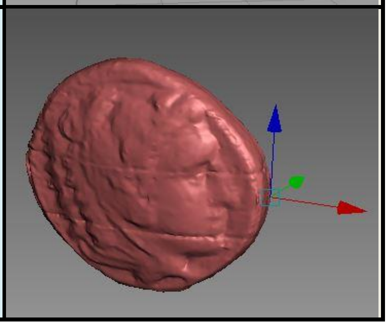
Artec Studio is utilized for scanning and post processing the 3d obtained data. So, the part is subjected to scan by use of laser and by exporting the scanned surfaces in Artec Studio the manipulation of those data for the reconstruction of the part can be achieved by using several tools provided. Artec will be used for the deviation analysis of the coins and dies later on.

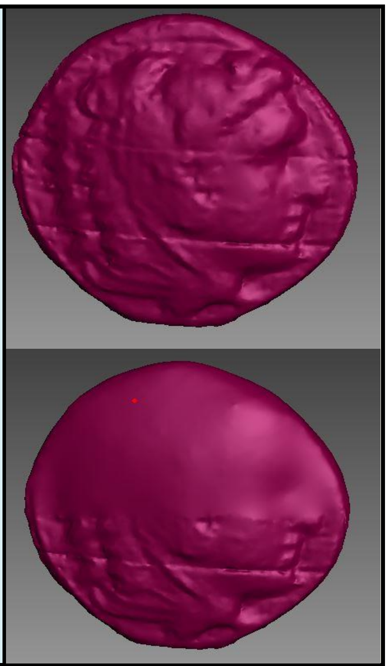
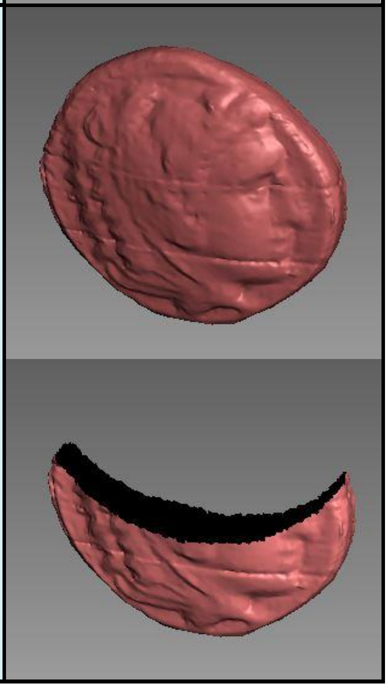
7.1. Introduction to Artec Studio

At Table 7.1 some indicative commands for post processing the obtained 3d data are depicted.

Table 7.1 Indicative commands for manipulation of the obtained 3d data

Command	Procedure	Found at	Visual Representation
Noise Eliminatio n	Elimination of noise derived by scanning process	Open_Editor_Eraser_ Cut off plane selection	

Align	Aligning the scans. The command can be performed automatically or manually by placing the number of needed pins for conducting the alignment	Align Tab_New Pair or Auto Alignment	   
Transformation	**moves-rotates-scales the object by moving the object along the x y z axis**	**Open_Editor_Transformation Tool**	

Smoothing Brush	**Softens the surface's shape by selecting the desired region**	**Open_Editor_Smoothing Brush**	
Eraser	**Erase of unwanted elements or portions of the object by selecting the desired portions to be removed**	**Open_Editor_Eraser**	

8. GREAT ALEXANDER’S SILVER TETRADRACHM

At this chapter the historical background of coinage as mean of transaction in ancient trades will be presented.Furthermore, information regarding the examined coin,the silver Tetradrachm of Alexander the Great and the dominance of it to commercial trades. Eventually, the scanning and post process of the coin with use of Next Engine Scan Studio will be presented along with the export of it as *stl format.

8.1. Coinage as mean of transaction in antiquity

The exchange of products before coinage facilitated the first communities to their survival. Agricultural products, animals, shells and leather were accepted as mean of transaction. In general, as much rare something was, much more valuable it was also. The price was set up depended on the role, abundance and utility of each product. During the inhabitance of humans in permanent residences the economy turned to be agricultural as well as husbandry. Animals were mainly used in commercial trades and this is more obvious if we take into consideration that in “The Iliad” the brassy weapons of “Diomedes”’ are mentioned as «εννεάβοια», meaning equivalent to 9 oxen, while the gold ones were equivalent to 100 accordingly. Mainly in Mesopotamia and Egypt wealth was measured by the amount of cattle and ships that someone possessed. Since 3000 BC precious metals started to partially substitute animals for transactions. Inscriptions as archeological evidence witness laws, payments or even contracts which were transacted with weighed silver as reference measure. Less versatile and resilient, ring shaped at tripod shape or by weapon form and axes were offered at first as presents and used also as weight measure units. The dominant metals at that time were gold in the East, copper and brass in Italy, Sicily and Cyprus. In high demanding trades pieces of unprocessed metals were used and were weighed mostly by the Haldians, Phoenicians, Israelites and Egyptians. With the advent of 6^{th} century BC most of the Ionian city-centers are illustrating their city symbols and patron gods. Leaders during the Hellenistic period asseverated their earthly dominance while feudal lords and western Princes are engraving their figures to eternity. In Greece, trade existed from around 2600 BC. Archaeologists have found pottery and precious goods including gold, copper and ivory far away from their construction origin. These findings are proof that trading took place between Greek city-states – Egypt and Asia Minor. When these civilizations became weaker, trade declined and almost disappeared. The authors Homer and Hesiod provided the earliest written evidence of trade and merchants after 700 BC. International trade grew and spread across the Mediterranean Sea for which different social and political factors played a crucial role to this increase. Before 600 BC there was no monetary system in Greece so trade was largely conducted through the exchange of one type of goods for another in a "barter" system that worked well for millennia. Eventually, some goods came to be exchanged for large metal bars, such as the bronze or copper talent, which both parties agreed to a value on. The next step was to use metal rods or spits (an "ovolos" from which the «ovol» coin derives its name) .The "ovol" as mean of transaction was invented by the king of the Greek city/state of Argos "Faidon". He was the one that established the use of metal as currency with an "ovol" shape. The initial use of an "ovol" was for nutrition reasons and was widely spread among people and this is the reason why it was so quickly adopted as a mean of transaction too. Each "ovol" was just as thick needed so that 6 "ovols" could be grasped by a human palm and this was equivalent to a "handful" as depicted at Fig.8.1.

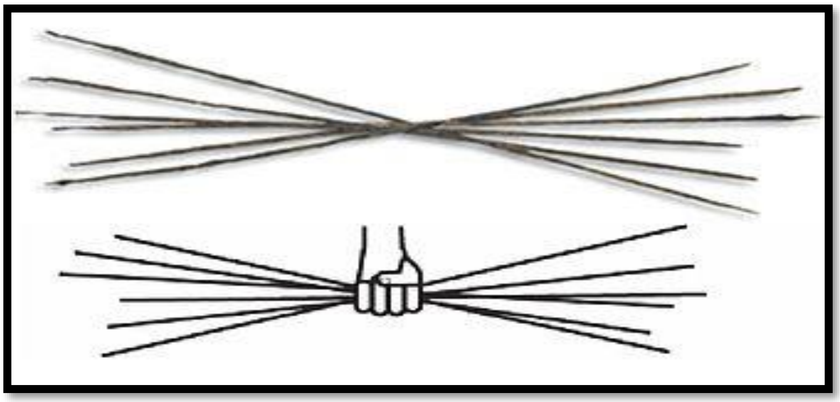


Fig 8.1 Depiction of a handfull
Ref. Screenshot taken by Google

From these bars and rods sprang the idea for a more portable and universal material which could be exchanged for any goods or service, coinage. https://argolikivivliothiki.gr/2011/05/16/%CF%84%CE%BF-%CE%BD%CF%8C%CE%BC%CE%B9%CF%83%CE%BC%CE%B1-%CF%83%CF%84%CE%BF%CE%BD-%CE%B1%CF%81%CF%87%CE%B1%CE%AF%CE%BF-%CE%B5%CE%BB%CE%BB%CE%B7%CE%BD%CE%B9%CE%BA%CF%8C-%CE%BA%CF%8C%CF%83%CE%BC%CE%BF/

8.2. Silver Tetradrachm of Great Alexander as the dominant currency

After his conquests the empire of Great Alexander was vast and consisted of many Greek city/states along with foreign countries (Fig.8.2), thus different tribes, cultures, religions and this was something that he had to handle. So, he encouraged his soldiers to marry non-Greek women and by this way to convey the Greek spirit and ideal. Regarding commercial trades the silver Tetradrachm (Fig.8.3) turned to be the main used coin which substituted the Athenian Tetradrachm which was the dominant form of transactions at that time .Great Alexander needed a strong currency for commercial trades in his vast empire, but this ought to be widely accepted by all the other Greek city/states.

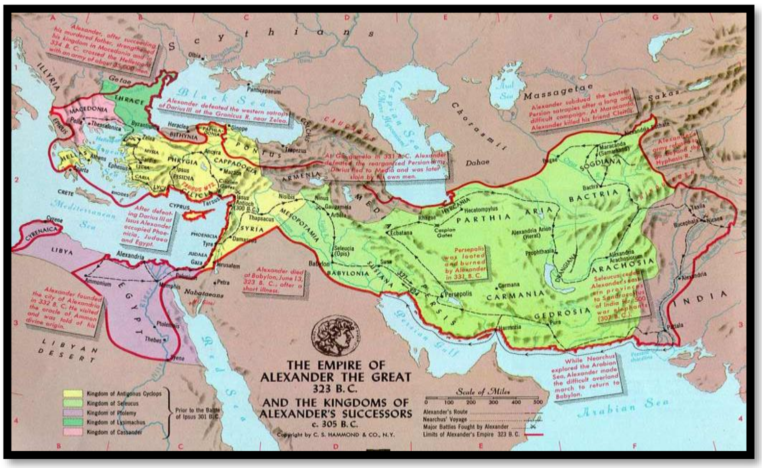


Fig 8.2 Great Alexander's Empire at 323 BC
Ref. Screenshot taken by Google

A big reform that Alexander the Great accomplished and was the milestone for the transition from the Athenian Tetradrachm to the Great Alexander silver Tetradrachm was the weighted rule –«σταθμητικός κανόνας» for the gold and silver coins .

Fig 8.3 Silver Tetradrachm of Great Alexander (336~323 BC)
Ref. Screenshot taken by Google

The Tetradrachm weighed approximately 17.2 grams but considered as 'pure' coin in lower weights also. Regarding the iconography, the silver coin was built at the same type, for the front view the head of Hercules as teenager wearing the "λεόντη", the skin of the fierce Nemean Lion killed by Hercules during his first labor- which is the Greek word for mane- was chosen. Born of the Greek god Zeus and made mortal, Hercules attained divine status by accomplishing 12 great tasks on Earth known as the “12 Labors of Hercules”. The idea of a man becoming a god obviously was an attractive influence-image for Great Alexander. The heroes face attributes are entrenched and must not be considered as Great Alexander’s portrait. As back side view the appearance of enthroned Zeus was chosen, in ¾ body attitude holding an eagle at his extended right arm and a scepter at his left arm. Furthermore, on the back side view we can observe the imprint “ΑΛΕΞΑΝΔΡΟΥ” (Fig.8.4) and since 325 BC at some imprints we also see “ΒΑΣΙΛΕΩΣ ΑΛΕΞΑΝΔΡΟΥ”(Fig.8.5). Supplementary, on the coins aliquot symbols or monograms of Greek city/states are present. Furthermore, the theme representation hasn’t been chosen by accident, it was known in Macedonian mint and the figures of Hercules and Zeus were widely accepted by all the other Greek city/states.

Fig 8.4 Silver Tetradrachm with “ΑΛΕΞΑΝΔΡΟΥ» imprint

Fig 8.5 Silver Tetradrachm with “ΒΑΣΙΛΕΩΣ ΑΛΕΞΑΝΔΡΟΥ” imprint

Ref. Screenshots taken by Google

This type of iconography was inducted somewhere in 333 BC when Great Alexander arrived at the regions of “Kilikia” and “Phoenicia”. The earlier type of imprints were the head of Zeus as the front side view whereas the back side view had two symbols, an eagle stepping upon a lightning bolt. Great Alexander’s coins and especially the silver Tetradrachm had major chronological propagation due to the fact that they were found even at the east Roman conquest, quantitative propagation due to the amount of coins made (approximately 60~80 million) but geographical also since they weren't propagated only in Greece and Asia, but also in the Balkans, Southern Italy, Central Europe and Africa. This occurred due to commerce, retired military generals or even because the local leaders of the forenamed regions adopted this popular type of coins.

https://theancientwebgreece.wordpress.com/2015/03/17/%CE%B7-%CE%B1%CF%81%CE%B3%CF%85%CF%81%CE%AE-%CE%BD%CE%BF%CE%BC%CE%B9%CF%83%CE%BC%CE%B1%CF%84%CE%BF%CE%BA%CE%BF%CF%80%CE%AF%CE%B1-%CF%84%CE%BF%CF%85-%CE%BC%CE%B5%CE%B3%CE%AC%CE%BB%CE%BF%CF%85/

8.3. Coin data manipulation

The scanned data of the coin are imported in Scanstudio as shown at Fig.8.6

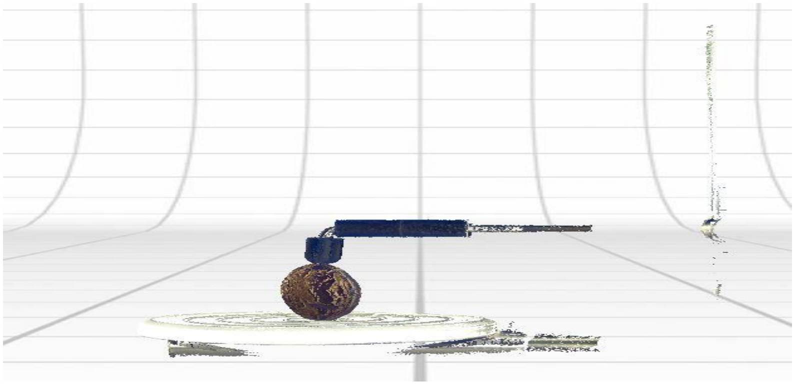


Fig 8.6 Import the coin in Scanstudio
Ref. Screenshot taken by NextEngine Scan Studio

The laser during scanning obtained besides the needed data (coin surfaces) unwanted portions of data also such as the bed platform of the scanner.For trimming these portions and lighten the file size the trim command will be activated and the trim selection at the subtabs will be enabled.The unwanted portions are marked and appeared in red color as shown at Fig. 8.7.

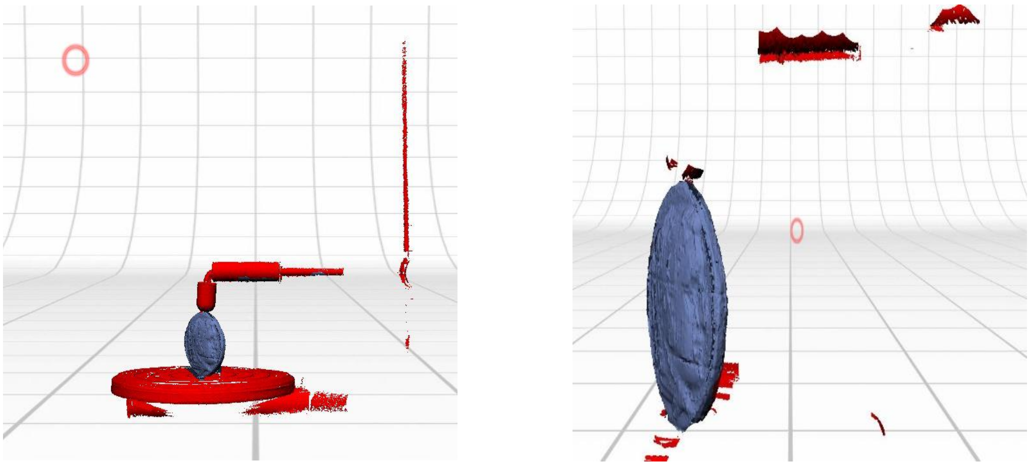


Fig 8.7 Selection of unwanted portions of scanned data for trimming
Ref. Screenshot taken by NextEngine Scan Studio

The trimming process will be repeated for the final noise elimination as depicted at Fig.8.8.

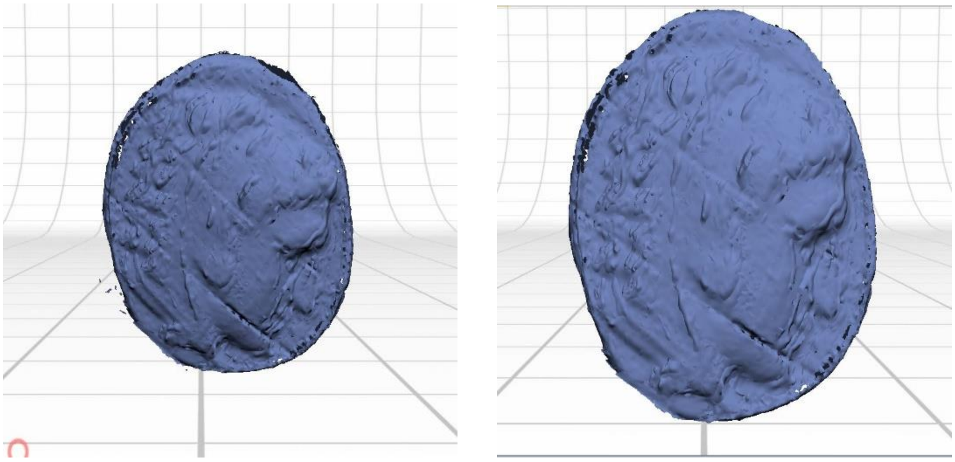


Fig 8.8 The coin after final noise elimination
Ref. Screenshot taken by NextEngine Scan Studio

With the noise eliminated the scans can be subjected to alignment so that a single family of scan to derive.

Alignment

This phase enables the user to align the multiple scans came from scanning stage by use of incorporated tools provided by the software for this purpose. Align option requires the emplacement of pins to similar obvious points upon the scans and results to a conjunction of those multiple scans in one scan. By pushing the align icon the Align command will be activated (Fig.8.9).

Fig 8.9 Align command enablement
Ref. Screenshot taken by NextEngine Scan Studio

The model can be renamed by the yellow bar as shown at Fig.8.10.

Fig 8.10 Model rename bar
Ref. Screenshot taken by NextEngine Scan Studio

With the Align command activated the screen is split in two, and two identical spaces with the first scan families of the coin will appear as shown in Fig.8.11.

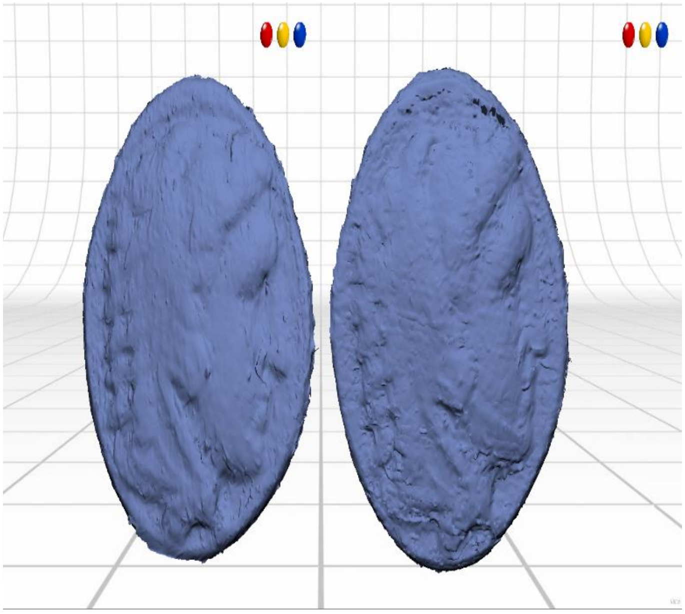
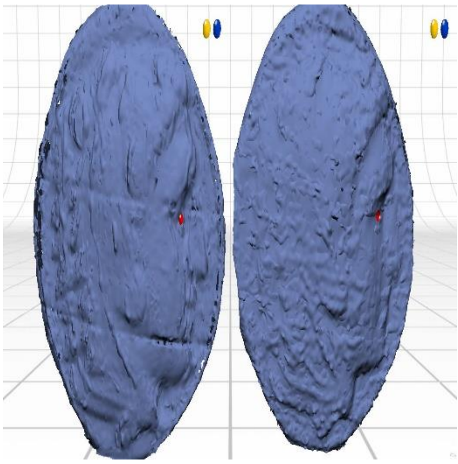
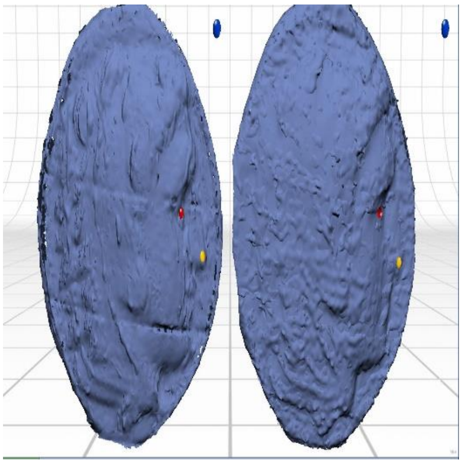


Fig 8.11 Initial interface of Align command
Ref. Screenshot taken by NextEngine Scan Studio

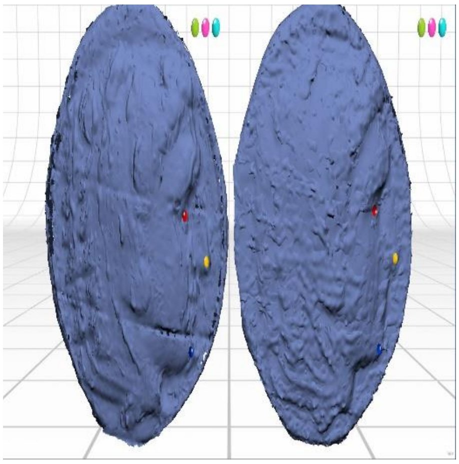
For proceeding with the alignment some pins should be placed at obvious points of the object which are the common entities in every scan family and will be used for stitching the multiple scans together. The minimum amount of pins to be placed so that the align command to be performed is minimum three as shown at Fig.8.12.



Emplacement of one pin



Emplacement of two pins



Emplacement of three pins

Fig 8.12 Align procedure
Ref. Screenshot taken by NextEngine Scan Studio

With the emplacement of the third pin the information tab notify us that the align command can be performed as shown at Fig.8.13

Fig 8.13 Emplacement of 3 pins for the alignment
Ref. Screenshot taken by NextEngine Scan Studio

Fuse

With the scanned faces trimmed and aligned the next step is the fusion of those multiple scan families in one. By the Fuse button on the main toolbar the Fuse command is activated (Fig.8.14) and the fuse toolbar pops up (Fig 8.15) enabling the settings.

Fig 8.14 Fuse command activation
Ref. Screenshot taken by NextEngine Scan Studio

Fig 8.15 Fuse interface
Ref. Screenshot taken by NextEngine Scan Studio

The toolbar consists of a slider which is appointed for the specification of the wanted deviation tolerance for the decimation. 0.00" simplification won't have any effect on the data but as the simplification slider increases the value of tolerance the model will be simplified and the file size will get smaller. For the coin fuse process the deviation tolerance will be left at 0.0025". Fusion settings gives the ability of automatic manipulation of the align errors ,such as holes, or water tight models, or customizing the resolution ratio and enables blending texture as shown at Fig 8.16.

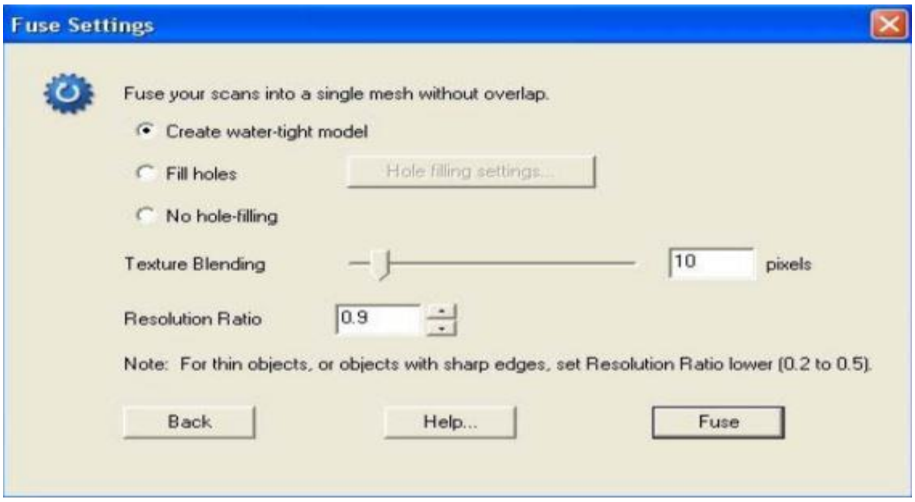


Fig 8.16 Fuse advance settings
Ref. Screenshot taken by NextEngine Scan Studio

For the best inspection of the overlapped surfaces the Hole Filling Slider inspects the circumference size of the holes to be filled. Texture blending is accounted for brightness variations and by a slider the amount of blending textures to be performed is controlled. The Resolution Ratio determines the new average vertice length in relationship to the current one. For the coin the resolution ration was set to 1.0. Values less than 1 will decrease your triangle size. Values greater than 1 will increase your triangle. When the desired configurations regarding fusion are set the process is then performed. as shown at Fig.8.17.

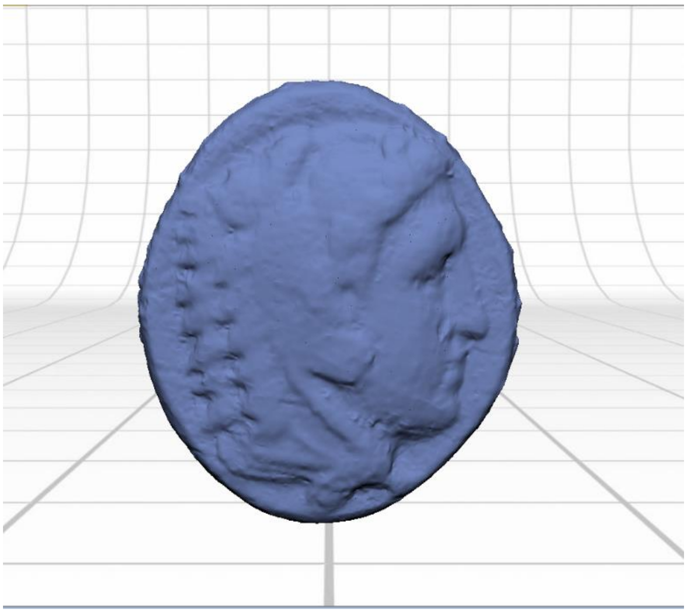


Fig 8.17 The coin after Fuse command
Ref. Screenshot taken by NextEngine Scan Studio

8.3.1. Export as *stl format

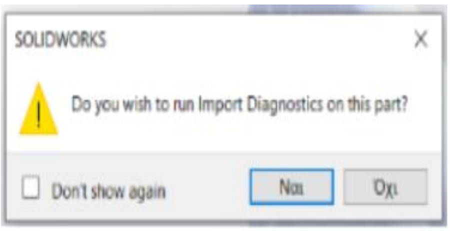
The coin will be exported as *stl format file in order to further manipulated by choosing the stl format icon in the output toolbar as shown at Fig.8.18.

Fig.8.18 Export of the coin data as *stl format
Ref. Screenshot taken by NextEngine Scan Studio

9. MOULD DESIGN USING SOLIDWORKS

The *igs format derived from NextEngine ScanStudio is imported in Solidworks. When the part is loaded a pop up window prompts the user to import Diagnostics for identifying faces or gaps that need repair as shown at Fig.9.1. From the point which diagnostics identified and repaired all faces the procedure will be held initially by creating a new coordinate system and the export of the part at particular format in order the coordinate system to be activated, Furthermore, the manipulation of the coin and the export of it as *sldprt format will follow and finally the mould design process on Assembly mode will conclude this chapter.

9.1. Positive die design process



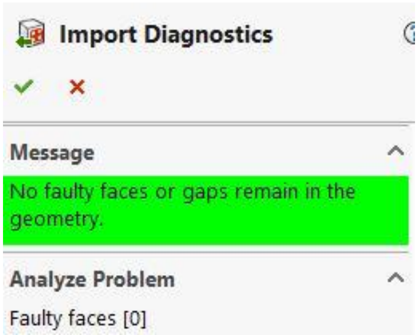


Fig 9.1 Import Diagnostics depicting no gaps or faulty faces existence
Ref. Screenshot taken by Solidworks

Due to the fact that the coin's origin doesn't match with the default coordinate system of Solidworks and as a result the default planes are not incorporated in the coin as shown at Fig. 9.2.

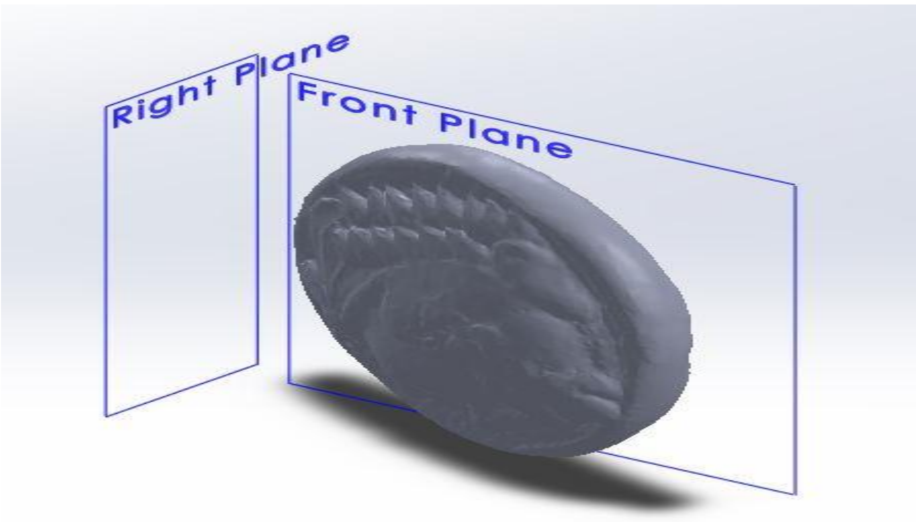


Fig 9.2 The imported coin with arbitrary Front, Right, Top plane
Ref. Screenshot taken by Solidworks

A new coordinate system is mandatory since it's not possible to design at any of the planes. The execution of the command though requires a point which will be the origin and three lines which will depict the orientation of x y z axis. First, for defining the point of the new origin the 3D sketch mode should be activated as shown at Fig.9.3 for activating design in space.

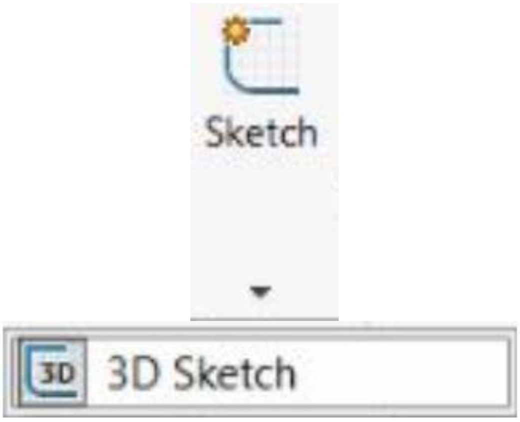


Fig 9.3 Use of 3D sketch for positioning the new origin on the coin
Ref. Screenshot taken by Solidworks

The coin will be rotated and positioned in a way that the back view will face the screen. Two points will be pinched upon the approximate center and at 90o degrees at the cognitive x axis of the coin back view (Fig.9.4).

Fig 9.4 Emplacement of arbitrary points upon the coin
Ref. Screenshot taken by Solidworks

With the points positioned a new plane with use of those two points can be created and will be parallel to the back view. At the new plane two construction lines will be drawn perpendicular the one to the other and will be used for the orientation of the x-y- axis. The next step is to create the new coordinate system. In order to do so the command will be activated under the Reference Geometry Tab (Fig.9.5).The construction lines will depict the x-y orientation while the mutual point of those lines will be chosen as the origin for the new coordinate system (Fig.9.6-9.7).

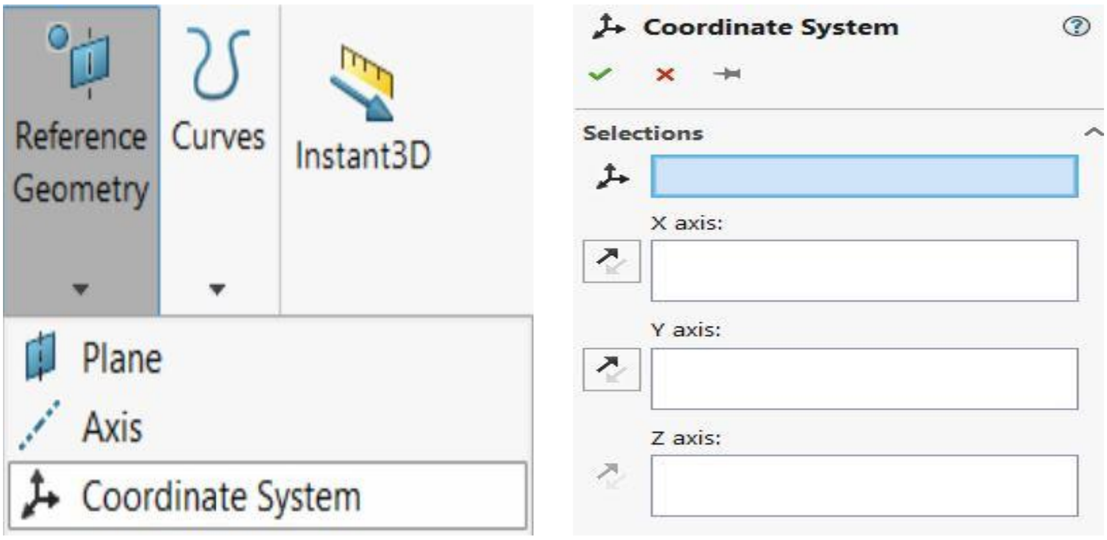


Fig 9.5 New Coordinate System Command
Ref. Screenshots taken by Solidworks

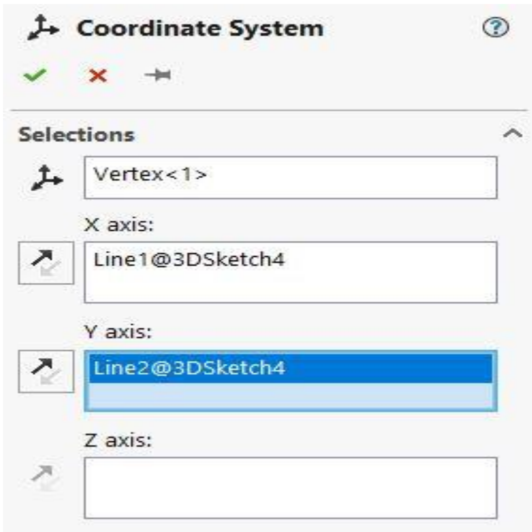


Fig 9.6 Depiction of the construction lines

Fig 9.7 Origin, x y axis selection as orientation tool

Ref. Screenshots taken by Solidworks

Even though the part is appointed with a new coordinate system this is not activated yet. In order this to take place the part must be saved in other format so that the new coordinate system to be enabled through it. The chosen format is the *sat extension and by the options Tab the created coordinate system can be set as default (Fig.9.8).

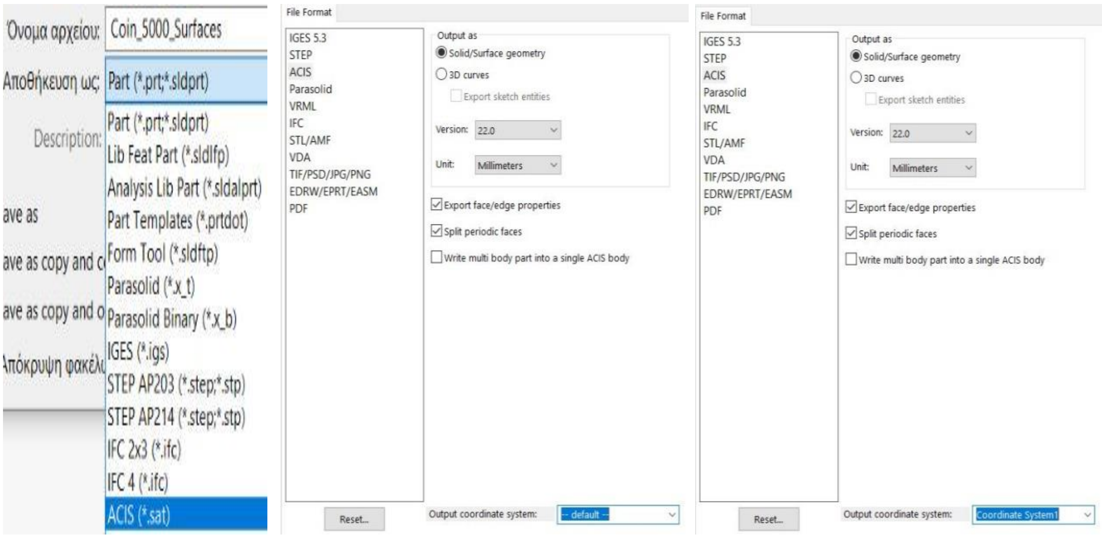


Fig 9.8 Save as *sat extension
Ref. Screenshot taken by Solidworks

The new *sat extension will be re opened and the coin will be imported with the new coordinate system present but in active state as well as depicted at Fig.9.9

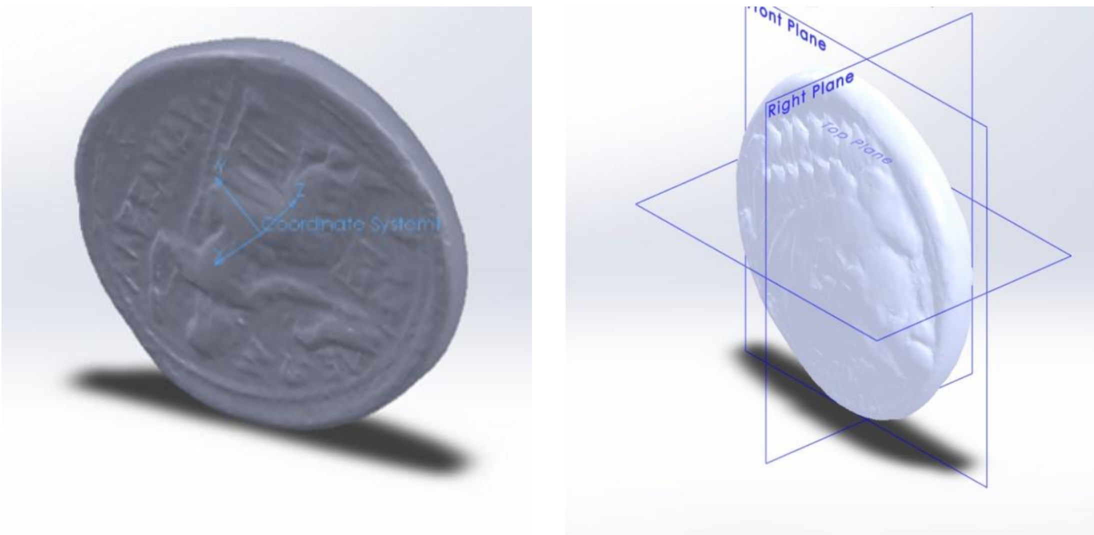


Fig 9.9 The coin with new coordinate system and design planes
Ref. Screenshot taken by Solidworks

For the mould creation the coin should be split in two halves so that the positive and negative dies to be created. This will happen by creating a new plane parallel to Plane

1 which was created for the coordinate system and will be positioned at the approximate middle of the coin thickness (Fig.9.10).

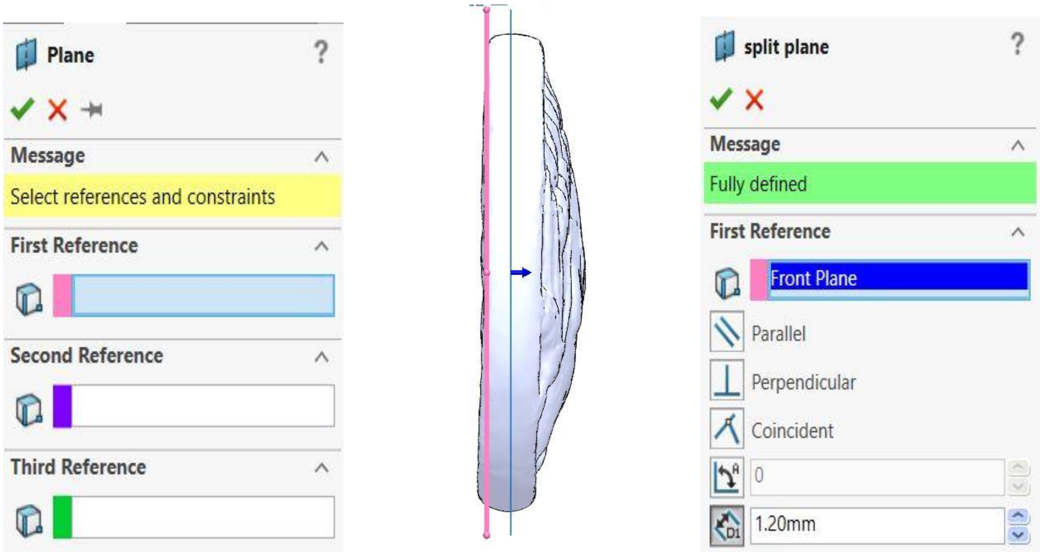


Fig 9.10 Split plane command execution
Ref. Screenshots taken by Solidworks

Split plane will be the reference plane for split process which will actually divide the coin in two halves and two solid bodies will be created and renamed to positive and negative die accordingly as shown at Fig.9.11

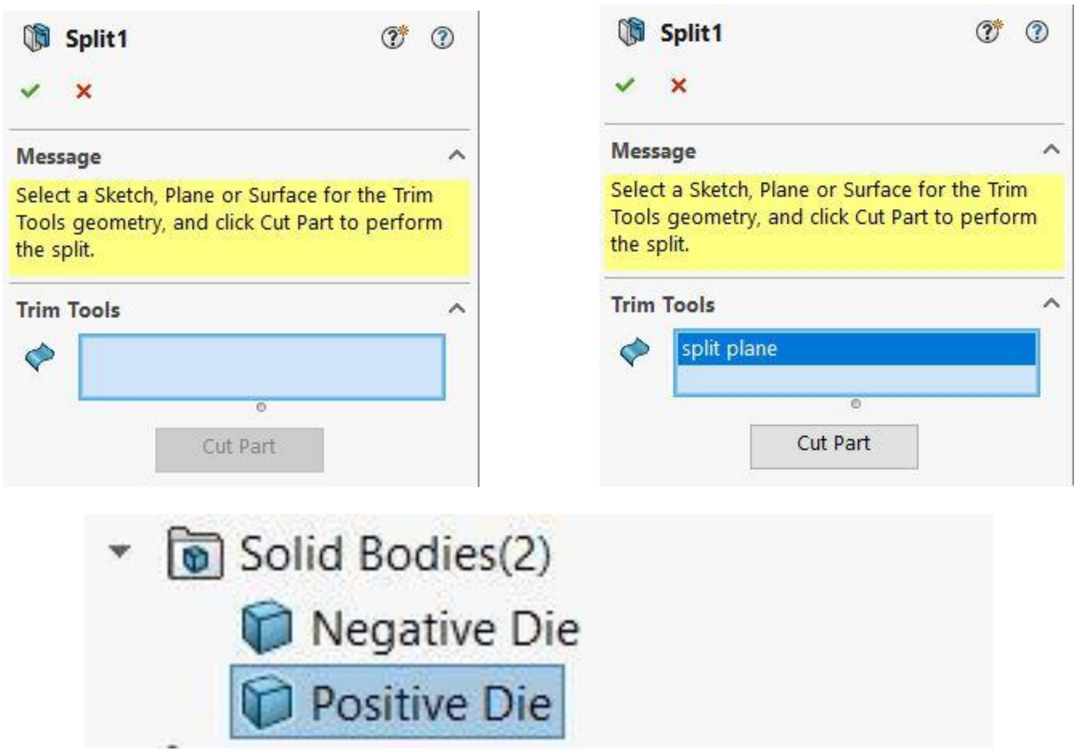


Fig 9.11 Split process resulted to two solid bodies
Ref. Screenshot taken by Solidworks

The coin is now ready for the mould design process. Even though Solidworks provides a specialized Tab for mould creation as shown at Fig.9.12 the mould couldn't be created by this automatic process so the mould will be constructed manually. The coin first must be saved as *sldprt extension in order to be reimported as base feature for a new assembly.

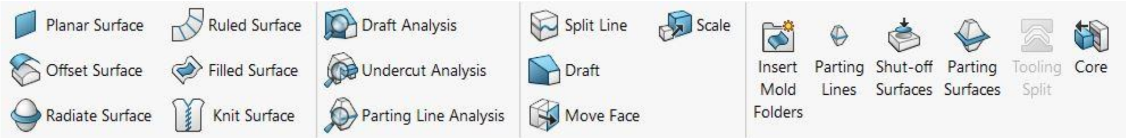


Fig 9.12 Mould tools Tab provided by Solidworks software
Ref. Screenshot taken by Solidworks

With enabling the Assembly Tab the first thing that has to be done is to import the coin as base component (Fig.9.13)

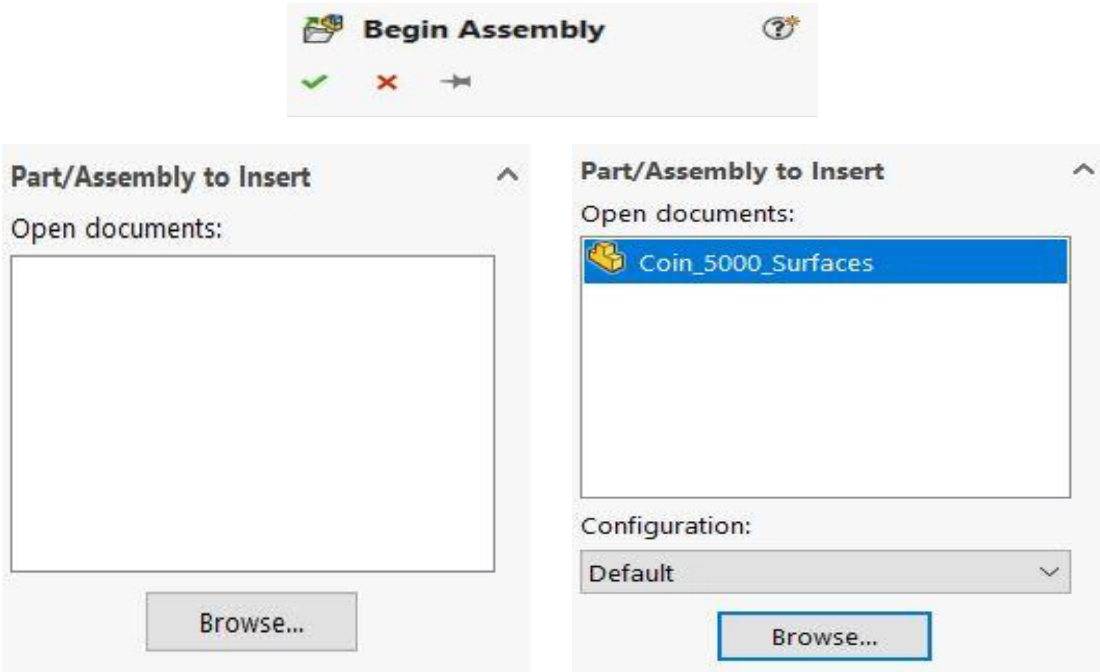


Fig 9.13 Insert Coin as base component in the assembly
Ref. Screenshot taken by Solidworks

For the design of each die the reference plane will be the split plane created above. For the positive die creation a new component will be imported in the assembly and will be renamed to “Positive Die” (Fig.9.14).

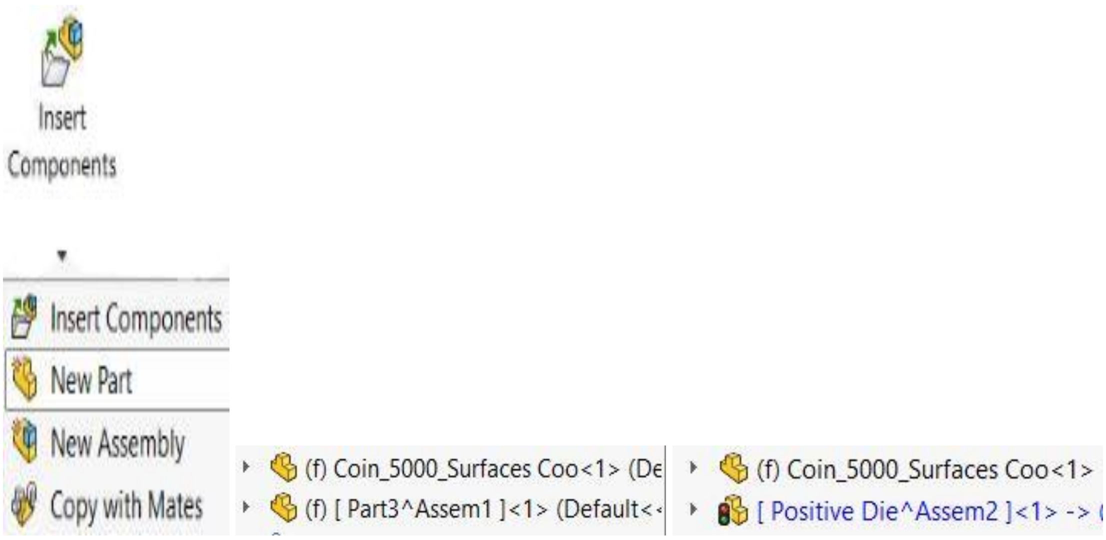


Fig 9.14 Positive Die folder induction and rename
Ref. Screenshot taken by Solidworks

With the folder induced a thing which ought to be specified is which plane should be activated by the software for enabling design. The reference plane as mentioned above will be the split plane. So, for designating the forementioned plane the coin folder at the design tree will be expanded and the split plane will be chosen as depicted at Fig.9.15.

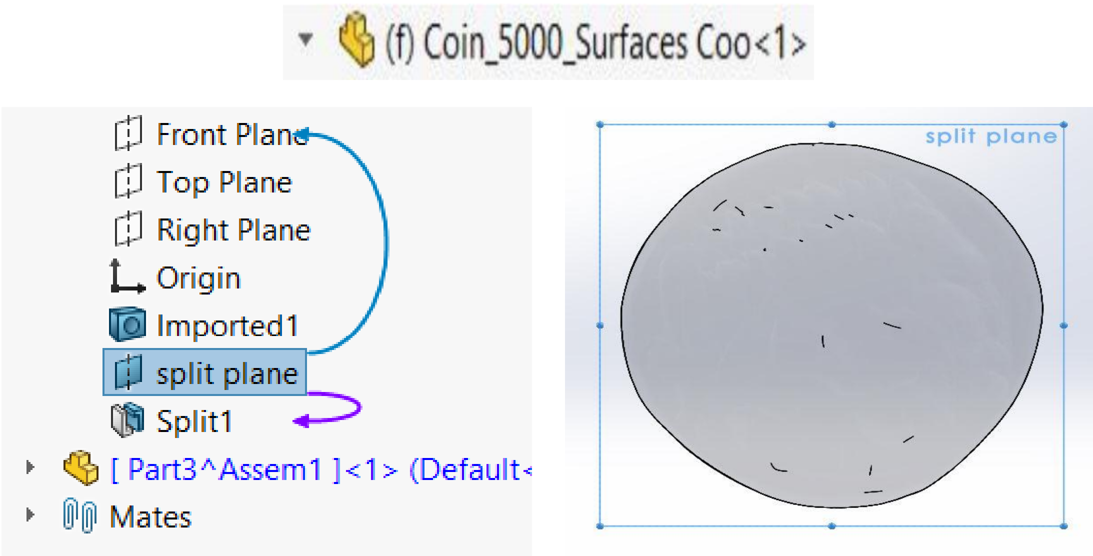


Fig 9.15 Enablement of split plane for design

Ref. Screenshot taken by Solidworks

When the split plane is designated the Edit Component icon is activated and furthermore the sketch toolbar allows the design of the box that will represent the Positive Die as depicted at Fig.9.16

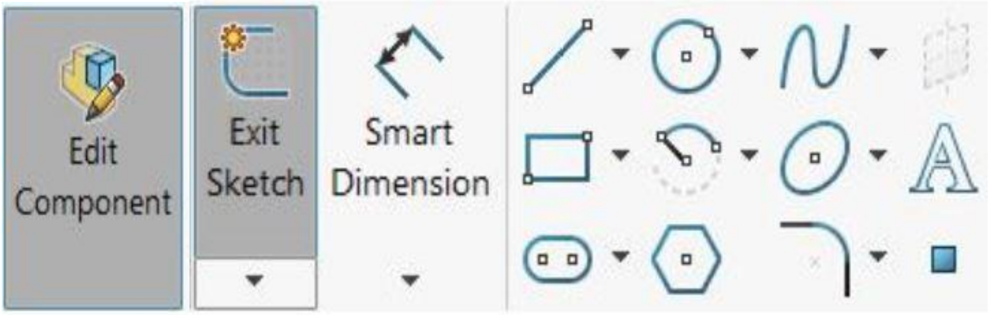


Fig 9.16 The sketch toolbar is activated for the mould design
Ref. Screenshot taken by Solidworks

The mould will be designed by a center rectangle which will overlap the coin front view surface as Fig.9.17 depicts and will be then extruded to create a 3d box.

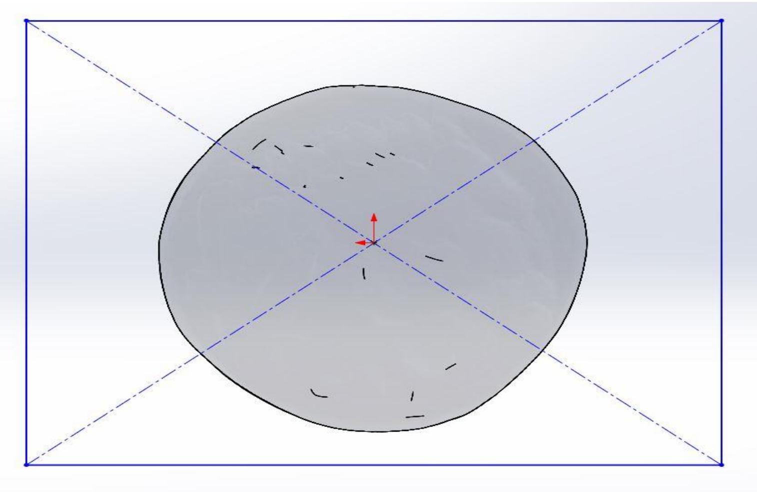


Fig 9.17 Initial box design
Ref. Screenshot taken by Solidworks

At this point when the box is dimensioned the affect of the arbitrary choice of point during the creation of the new coordinate system appears as shown at Fig.9.18

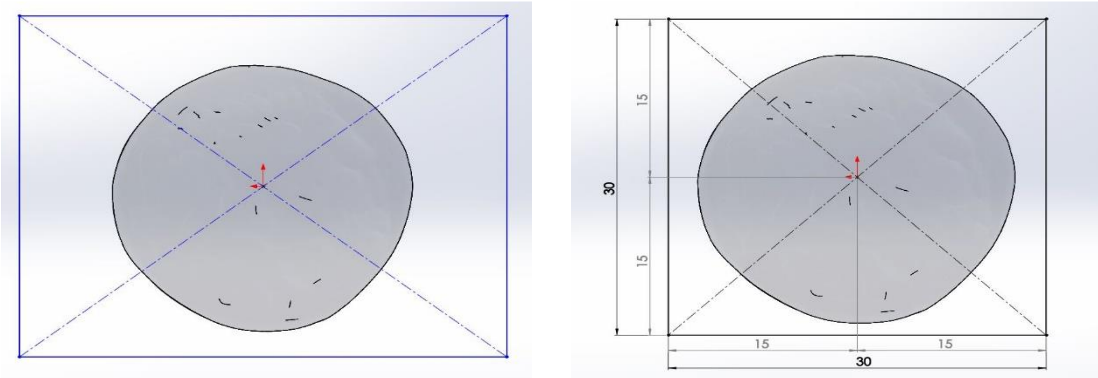


Fig 9.18 Design of the mould box and dimensional relation to the coin origin
Ref. Screenshot taken by Solidworks

From Fig.9.18 it's obvious that the mandatory arbitrary point chosen to be the origin for the new coordinate system resulted at unequal distance between the coin's circumference and the mould's upper and lower walls. In order the coin to be equally distanced to each wall of the die a new rectangle will be drawn without the use of the origin and the dimensions between the upper and lower walls compared to the origin will be modified accordingly as shown at Fig.9.19.

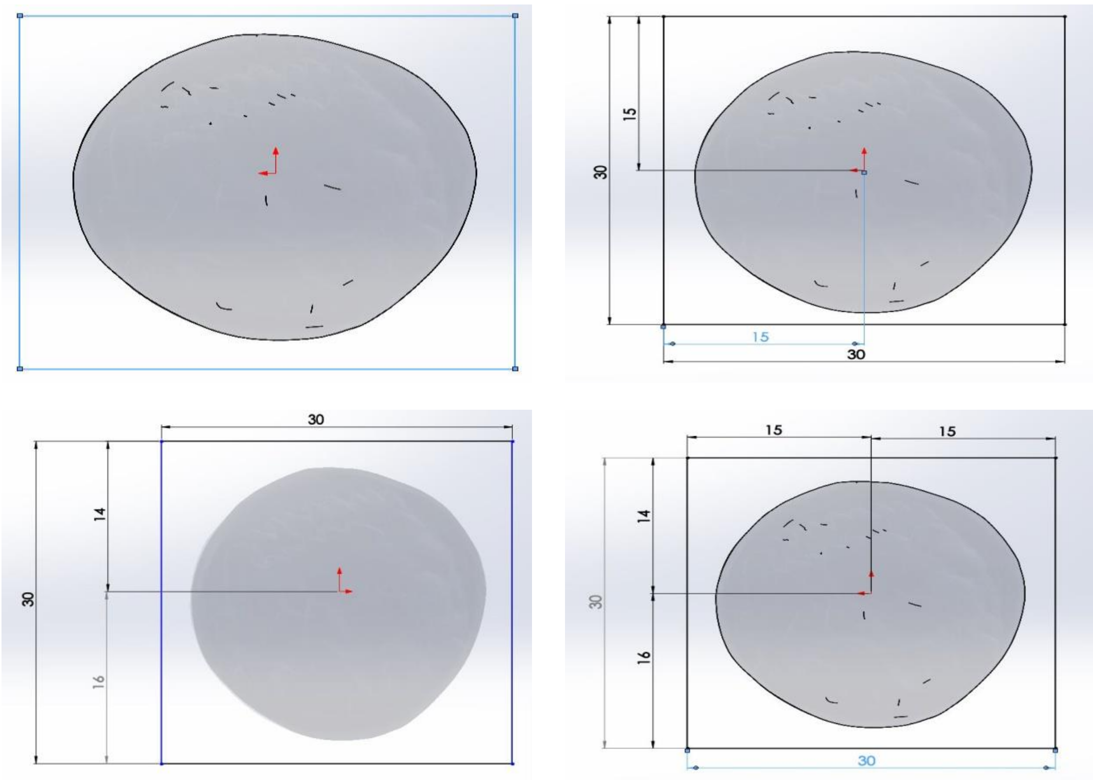


Fig 9.19 Box and dimensioning of the positive die
Ref. Screenshot taken by Solidworks

With the box designed and properly positioned compared to the coin the Boss Extrude command will be used for making the solid positive die. The extrude command will have as a starting point the split plane which was the plane in which the box was designed. The extrusion thickness will be set at 20mm as depicted at Fig.9.20

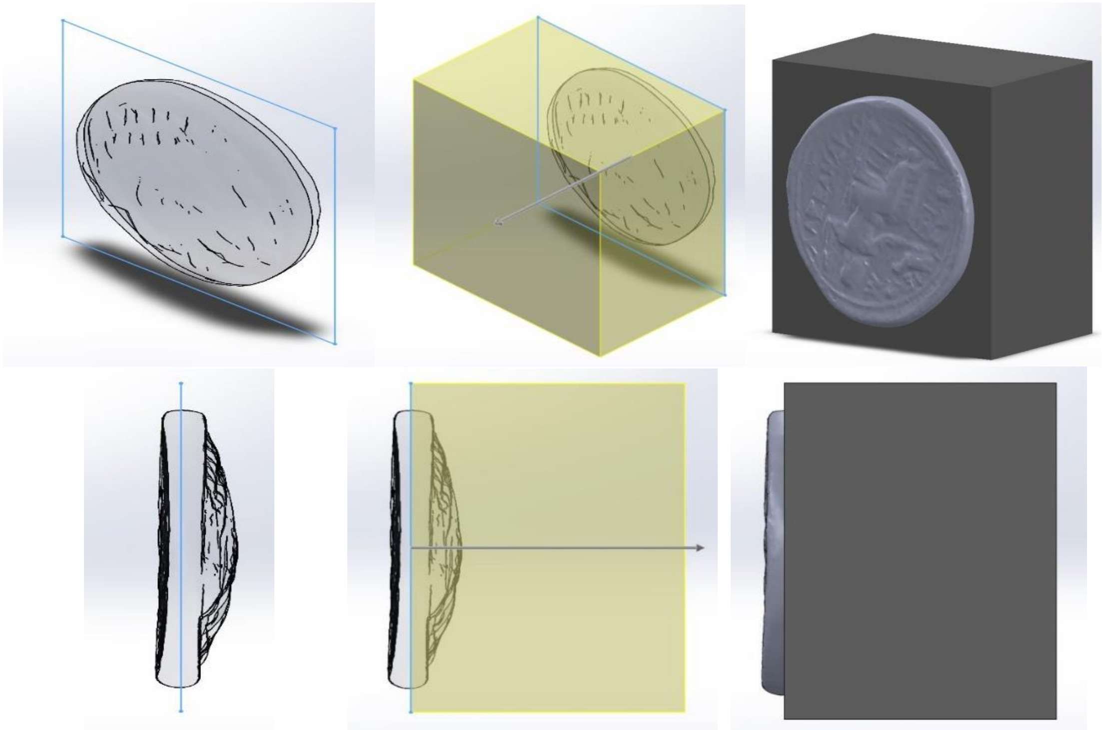


Fig 9.20 Boss Extrude command for the positive die (Trimetric-Right View)
Ref. Screenshot taken by Solidworks

Despite the fact that now the half coin is engraved in the solid box by use of exploded view we see that only a box was extruded without the details of the coin to be imprinted upon it as shown at Fig.9.21

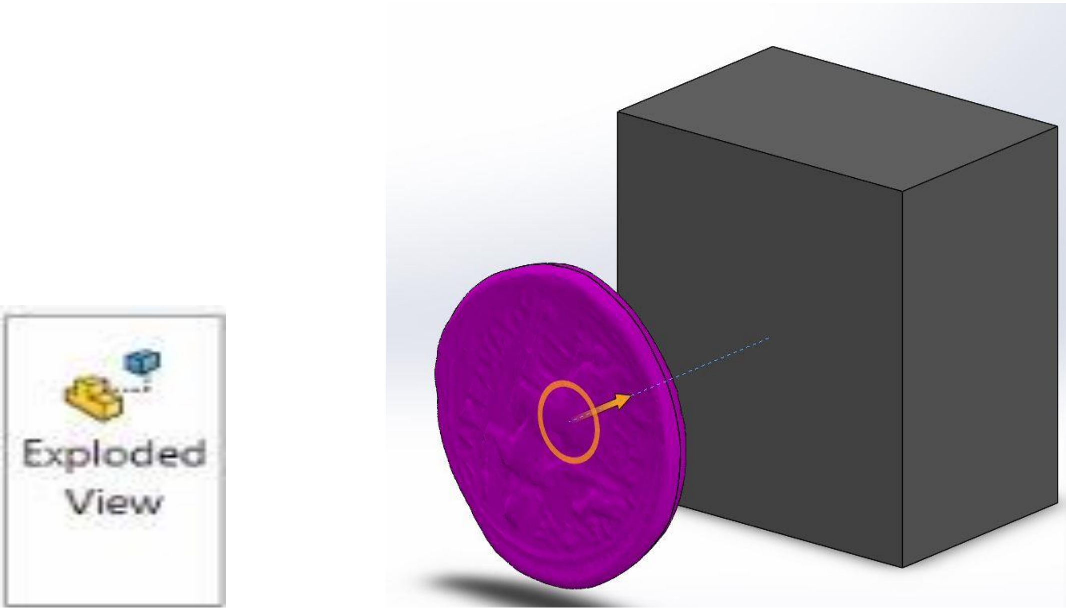


Fig 9.21 Exploded view depicting no imprint result
Ref. Screenshot taken by Solidworks

For engraving the coin iconography upon the die the cavity command will be used with the coin to be the design component as shown at Fig.9.22

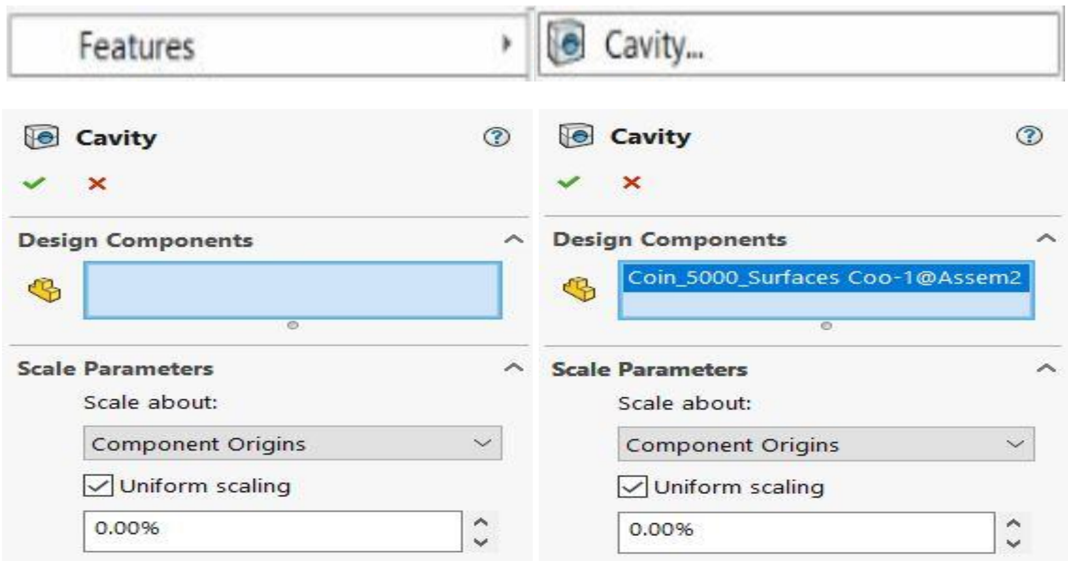


Fig 9.22 Deployment of Cavity command for positive imprint
Ref. Screenshot taken by Solidworks

With the command completed the exploded view will be used again for identifying the affect of cavity process as shown at Fig.9.23

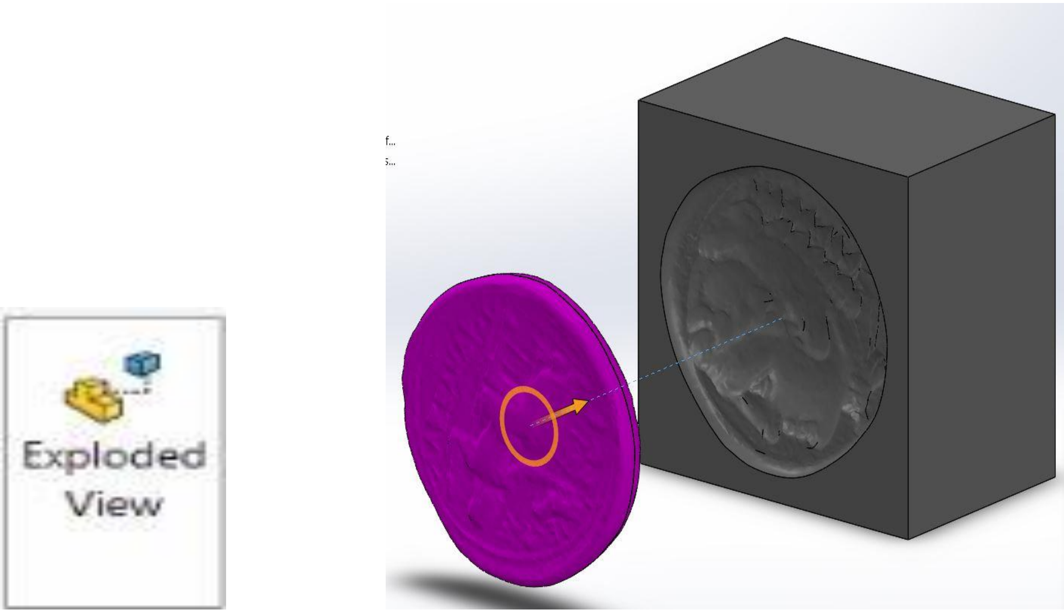


Fig 9.23 Exploded view depicting the imprint result
Ref. Screenshot taken by Solidworks

9.1.1 Export Positive Die as *stl format

The positive die is now ready and will be saved as separate part. This will happen by right click on the positive die folder and enabling the open part option which will activate the positive die at another window panel as shown at Fig.9.24

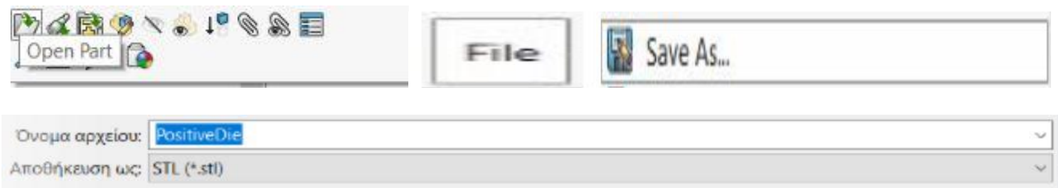


Fig 9.24 Positive Die Save as an STL file
Ref. Screenshot taken by Solidworks

The positive die is saved as a separate file and exported at *stl format as shown at Fig.9.25

Fig 9.25 Export the Positive Die as *stl format
Ref. Screenshot taken by Solidworks

9.2. Negative die design process

The procedure for design and extrude the Negative Die will be simplified using the positive die as reference feature. For the negative die design a new part should be added on the Assembly and then renamed as shown at Fig 9.26

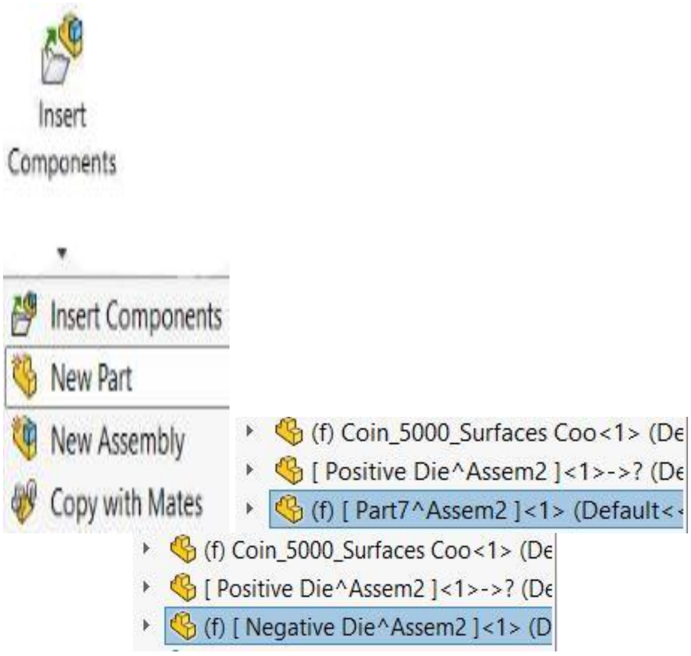


Fig 9.26 Negative Die folder induction and rename
Ref. Screenshot taken by Solidworks

With the folder induced it must be determined which plane should be activated by the software for enabling design. The reference plane as mentioned above will be the Split plane. So, for designating the forementioned plane the coin folder will be expand and the split plane will be chosen as depicted at Fig.9.27.

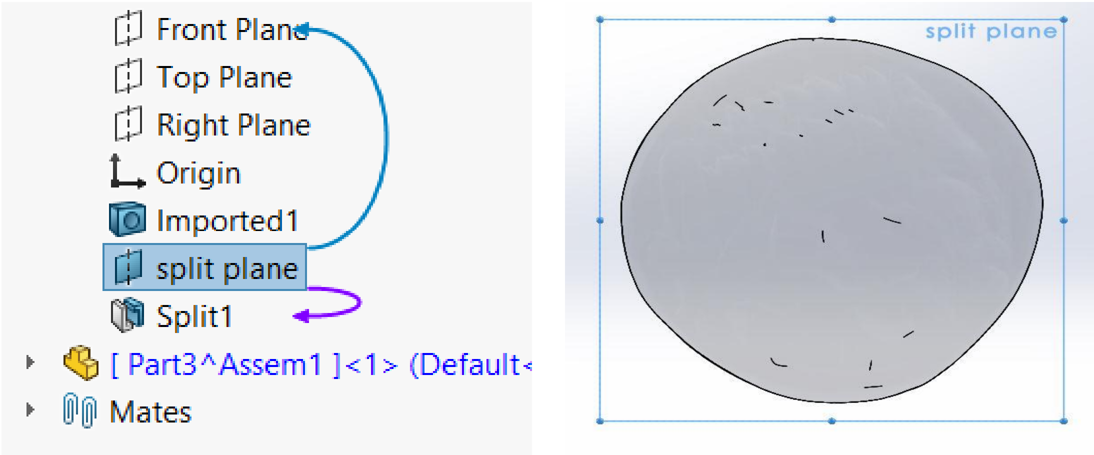


Fig 9.27 Enablement of split plane for design
Ref. Screenshot taken by Solidworks

When the split plane is designated the Edit Component Icon is activated and furthermore the sketch toolbar allows the design of the box that will represent the Negative Die as depicted at Fig.9.28

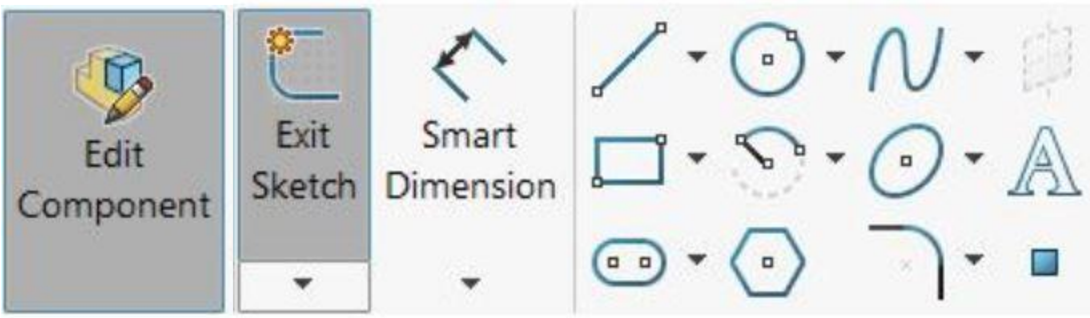


Fig 9.28 The sketch toolbar is activated for the mould design
Ref. Screenshot taken by Solidworks

For not wasting time following the same procedure for the design of the negative die as the positive die the circumferential lines of the positive die will used for designing the new box with use of convert entities command as shown at Fig.9.29

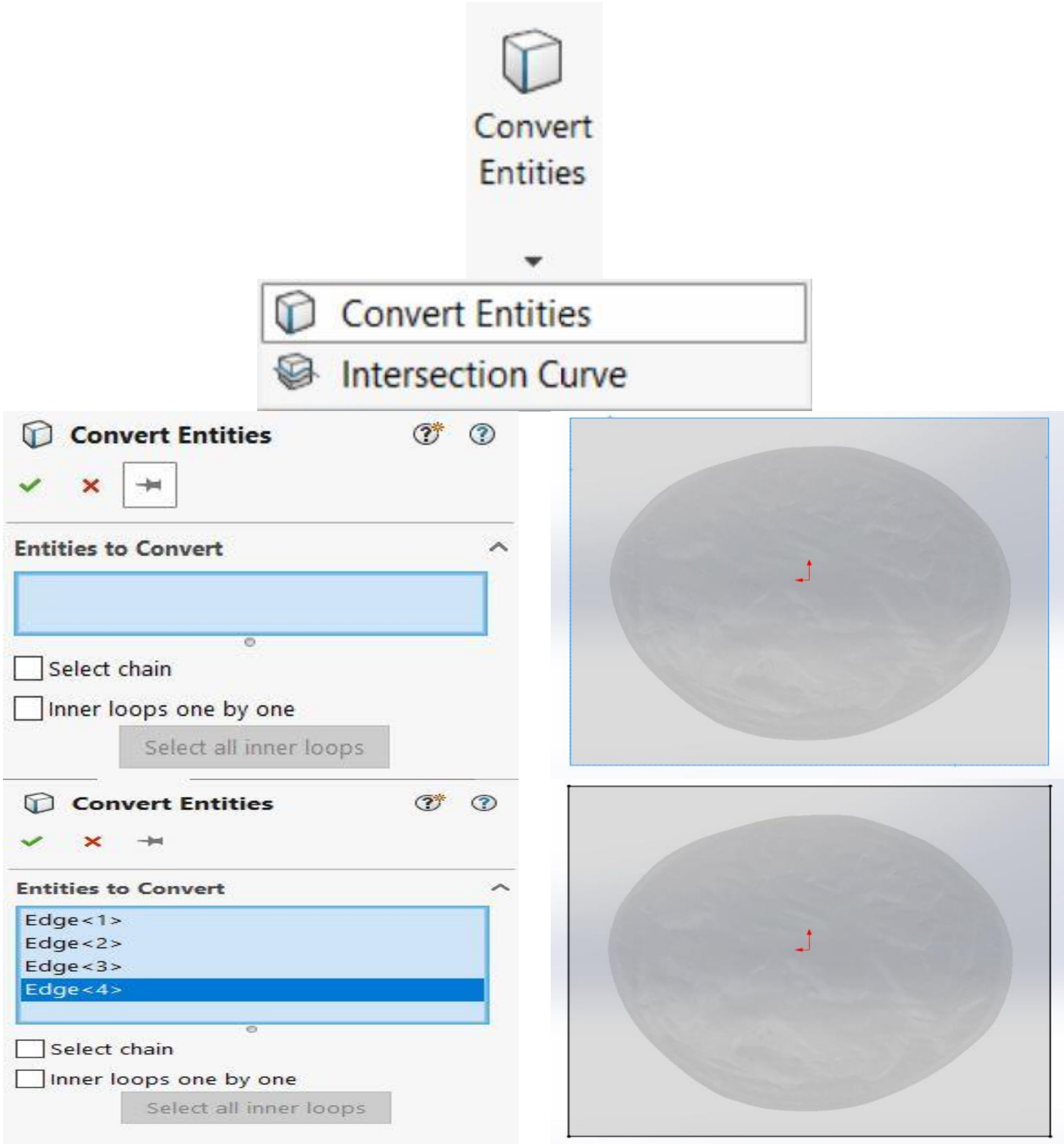


Fig 9.29 Design process of the Negative Die with use of convert Entities command
Ref. Screenshot taken by Solidworks

By Convert Entities command the 2D sketch of the negative die is completed. The box will now be extruded at a depth of 20 mm with use of Boss Extrude command as shown at Fig.9.30

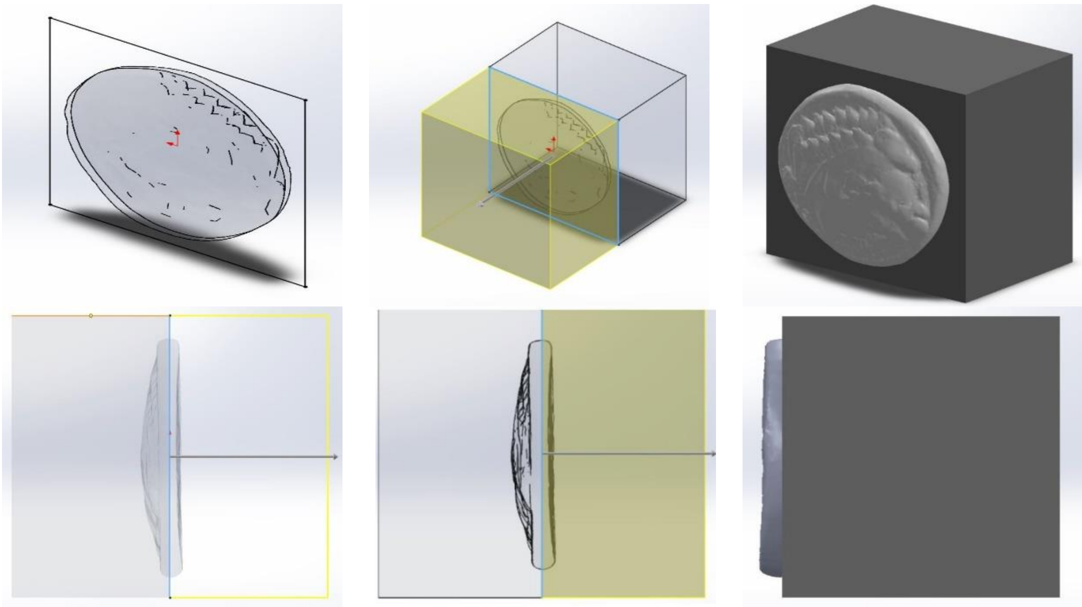


Fig 9.30 Boss extrude command for the negative die (Trimetric-Right view)
Ref. Screenshot taken by Solidworks

Once more despite the fact that now that the negative die box is extruded as a solid body containing the negative half of the coin by use of exploded view we see that only a box was extruded without the details of the coin to be imprinted upon it as shown at Fig.**9.31**

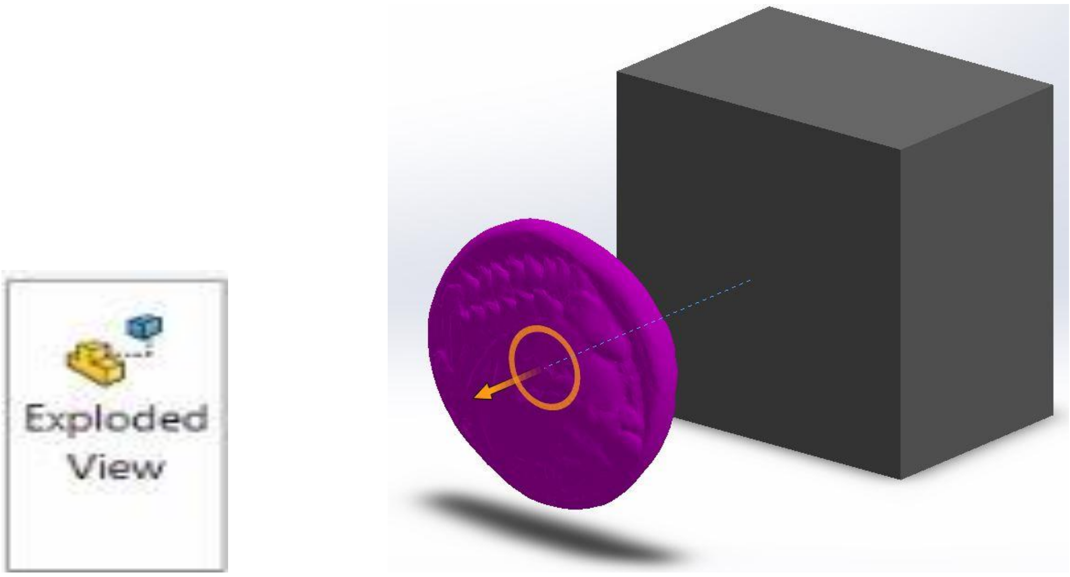


Fig 9.31 Exploded view depicting no imprint result
Ref. Screenshot taken by Solidworks

For engraving the coin iconography upon the die the cavity command will be used with the design component to be the coin as shown at Fig.9.32

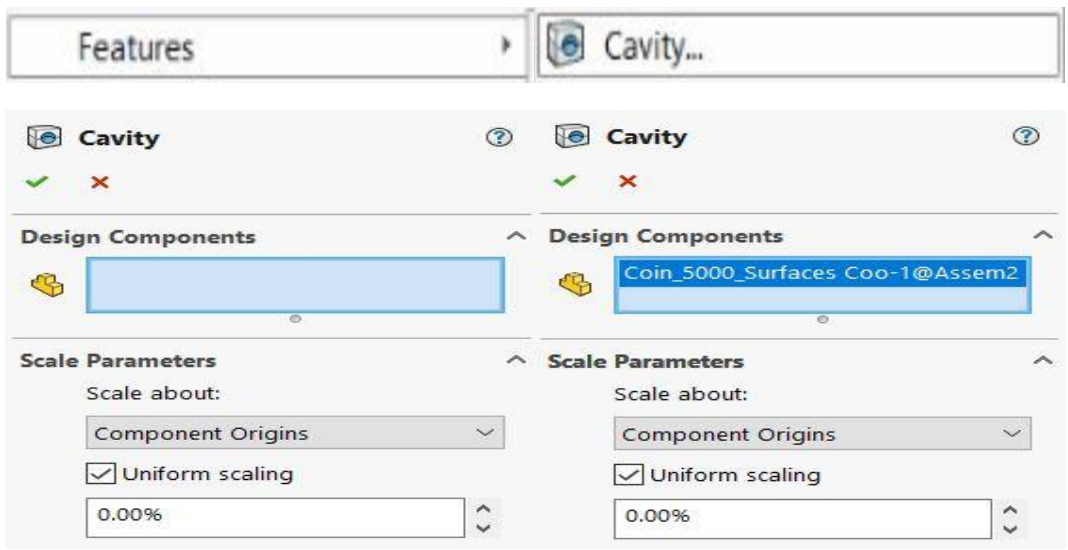


Fig 9.32 Deployment of Cavity command for negative imprint
Ref. Screenshot taken by Solidworks

With the command completed the exploded view will be used again for identifying the affect of cavity process as shown at Fig.9.33

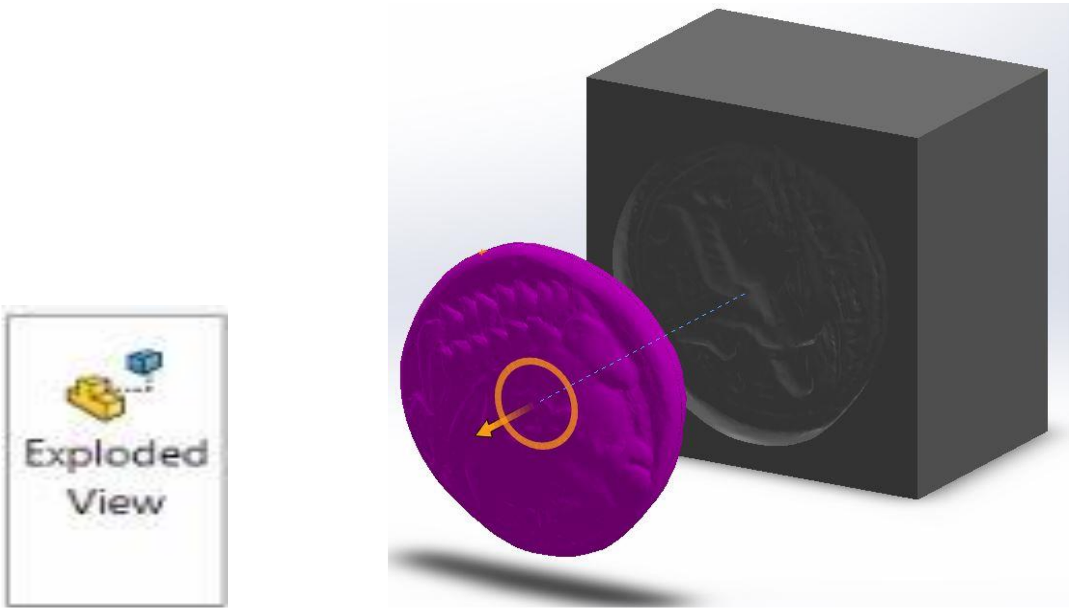


Fig 9.33 Exploded view depicting the imprint result
Ref. Screenshot taken by Solidworks

9.2.1. Export as *stl format

The negative die is now ready and will be saved as separate part. This will happen by right click on the negative die folder and enabling the open part option which will activate the negative die at another window panel as shown at Fig.9.34

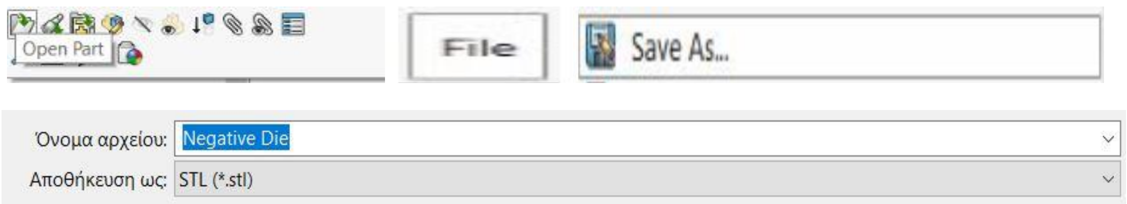


Fig 9.34 Negative Die Save as an STL file
Ref. Screenshot taken by Solidworks

The final dies and renders of the mould are depicted at Fig.**9.35**

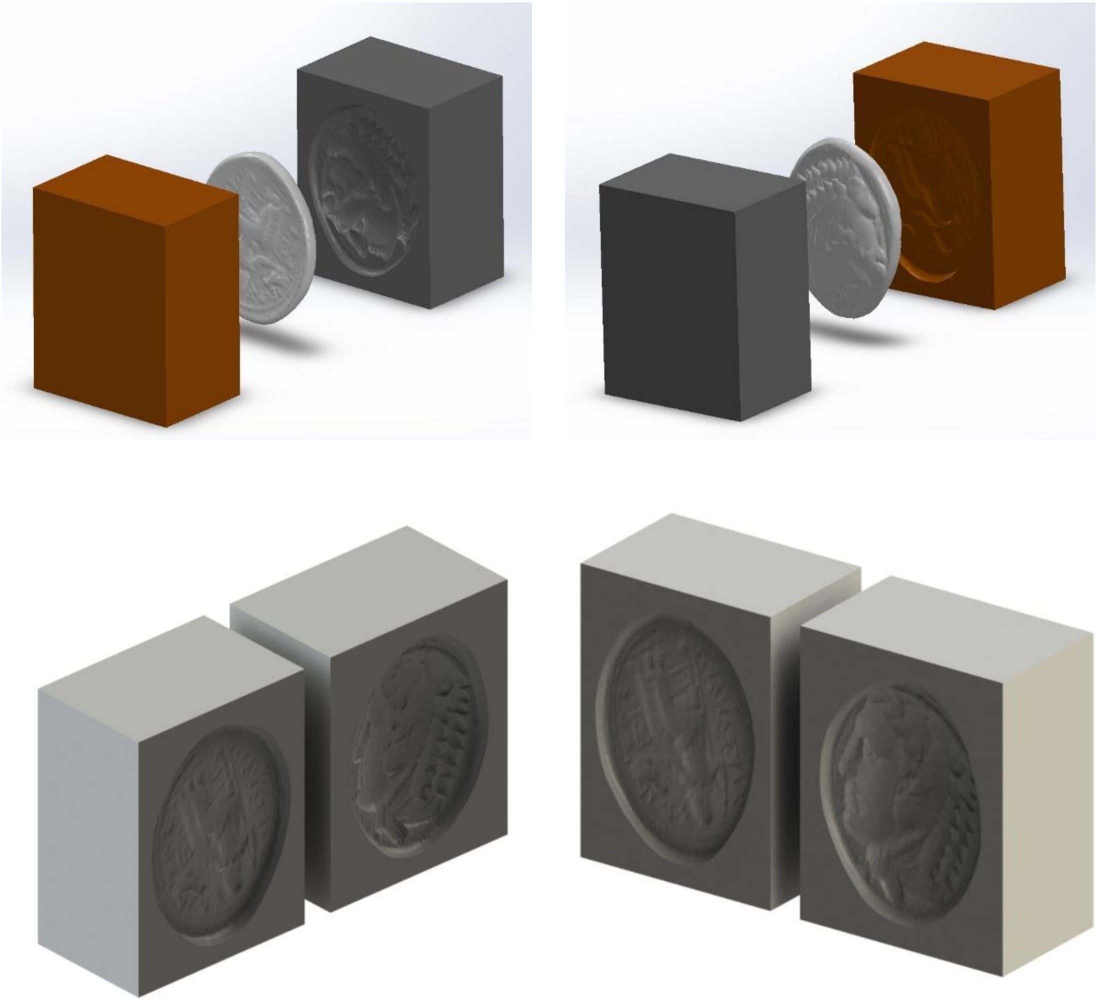


Fig 9.35 Final Assembly and Renders of the dies (Trimetric view)
Ref. Screenshot taken by Solidworks

10. G-CODE CREATION FOR THE SLA-FDM COINS AND DIES USING PREFORM +1 AND ULTIMAKER CURA 4.4

In this chapter the procedure of slicing the STL file for creating the g-code for the construction of the SLA and FDM coins and dies with use of Preform +1 and Ultimaker 4.4 respectively will be presented.

10.1. Parts preparation with Preform+1

10.1.1. Coin preparation

The model is imported in the built platform and repositioned as shown at Fig.10.1

Fig 10.1 Coin repositioned on the built platform
Ref. Screenshot taken by software

As mentioned above the presence of supports is mandatory. So, for the sake of presentation the supports emplacement will be done manually. By enabling the Supports command the coin turns in red color depicting the need of supports as shown at Fig.10.2

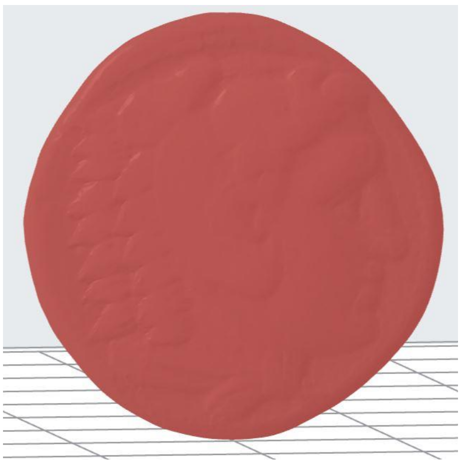


Fig 10.2 Supports command enabled

Ref. Screenshot taken by software

For placing the supports and since we need the surfaces untouched those will be placed at the circumference of the coin. After placing the 1st support the coin at this area retrieves its original color meaning that at this area the support is strong enough (Fig.10.3).The support emplacement will be repeated until the coin retrieves its initial color as shown at Fig.10.4.

Fig 10.3 Emplacement of 1st support
Ref. Screenshot taken by software

At this point the coin is equipped with enough supports so that it won't encounter any structure defects.

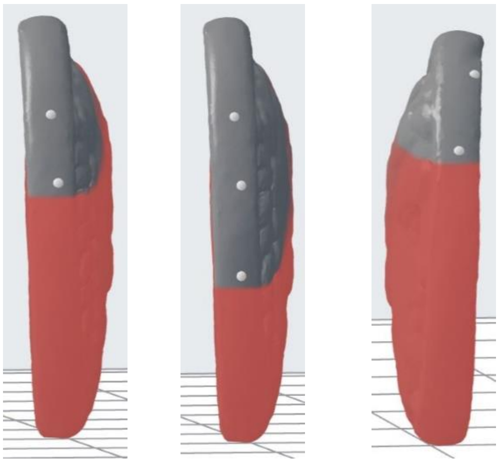


Fig.10.4 Emplacement of the needed supports for the structure
Ref. Screenshot taken by software

By clicking apply a preview of the coin on the built platform with the created supports is illustrated as shown at Fig.10.5

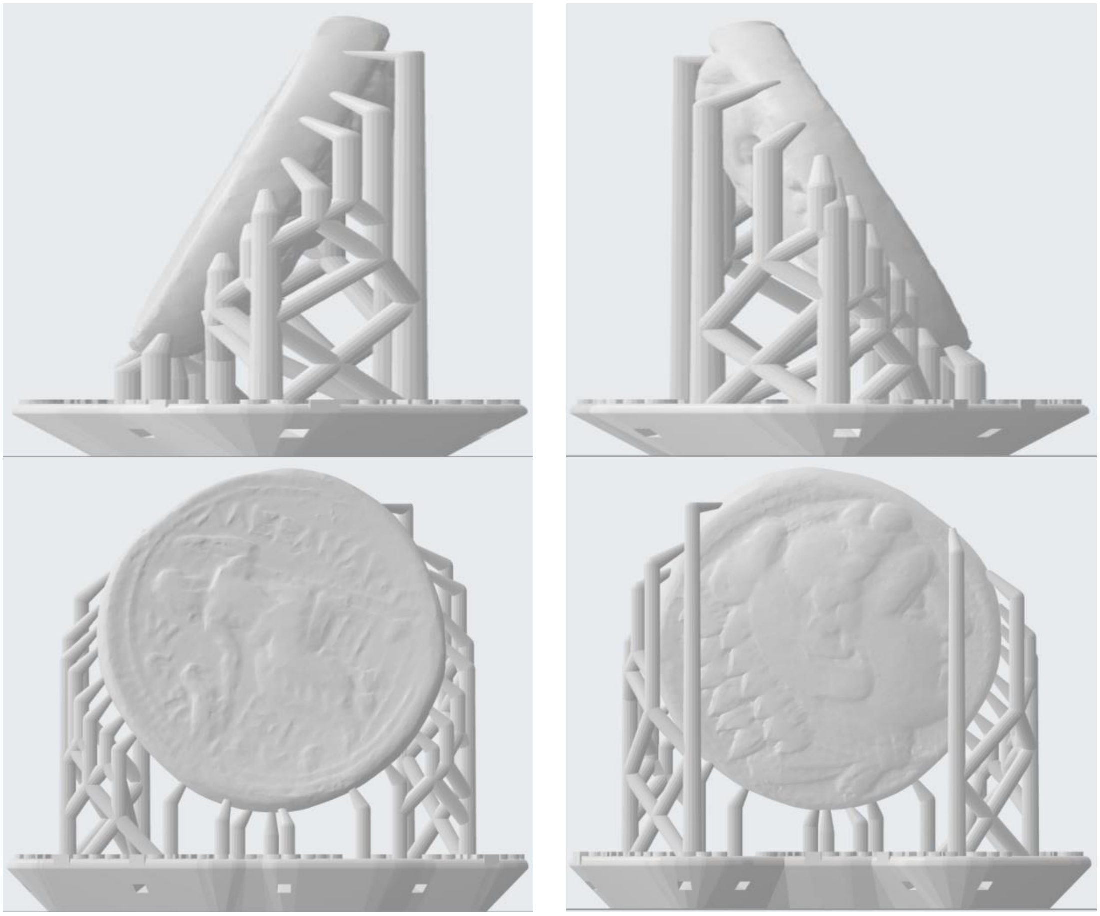


Fig 10.5 The coin with the supports structure
Ref. Screenshot taken by software

10.1.2. Negative die preparation

The model is imported in the built platform and repositioned as shown at Fig.10.6

Fig 10.6 Negative Die repositioned on the built platform
Ref. Screenshot taken by software

By enabling the Supports command the coin turns in red color depicting the need of supports as shown at Fig.10.7

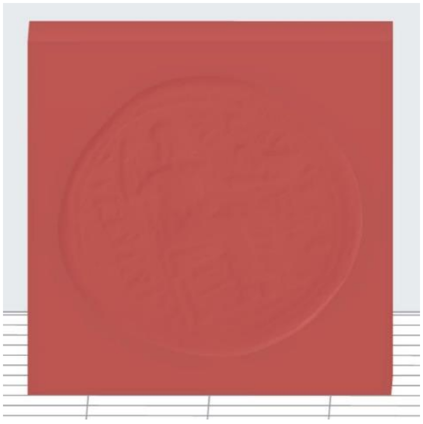


Fig 10.7 Supports command enabled
Ref. Screenshot taken by software

For placing the supports and since we need the surfaces untouched those will be placed at the circumference of the die. After placing the 1st support the die at this area retrieves its original color meaning that at this area the support is strong enough

(Fig.10.8).The support emplacement will be repeated until the die retrieves its initial color as shown at Fig.10.9.

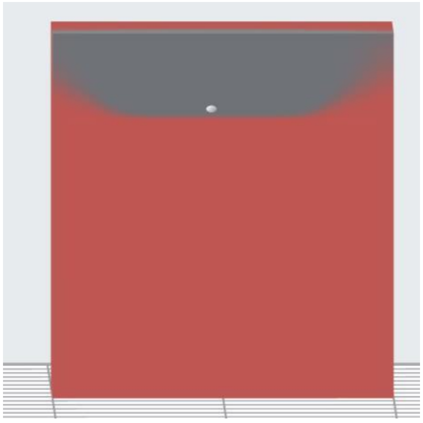


Fig 10.8 Emplacement of 1st support
Ref. Screenshot taken by software

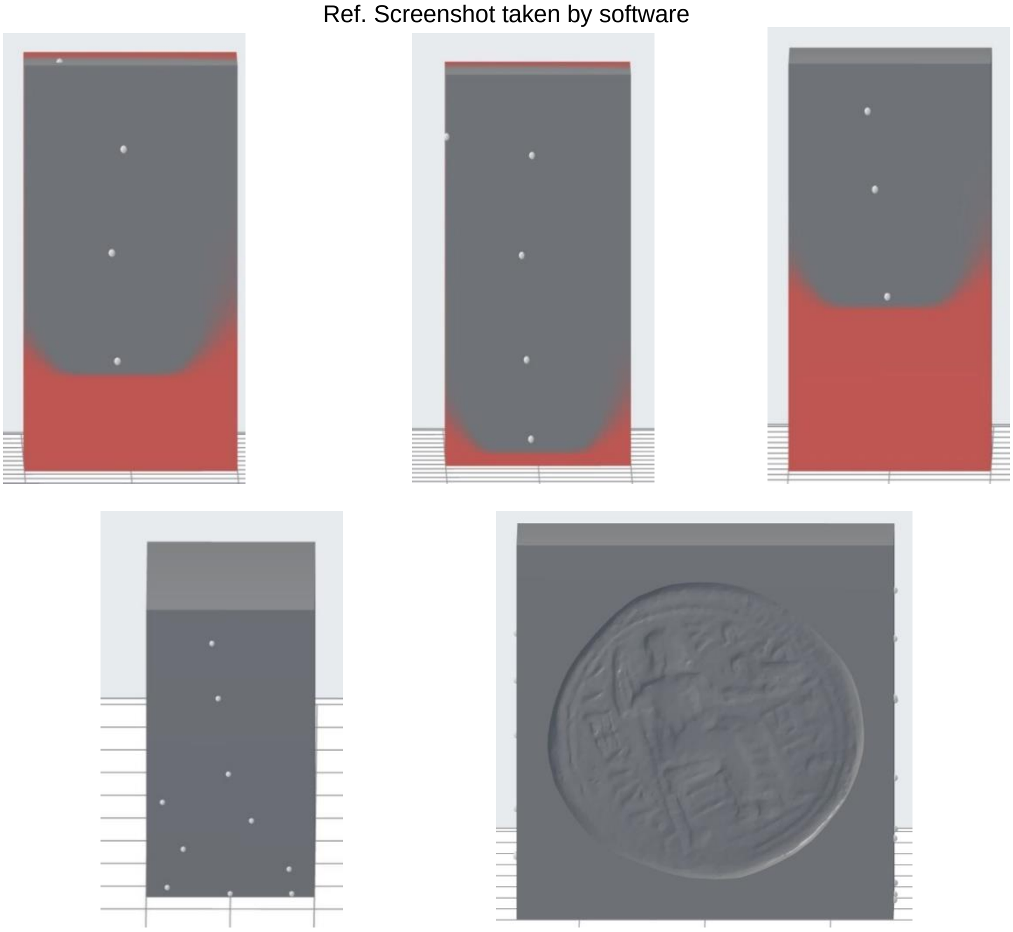


Fig 10.9 Emplacement of the needed supports for the structure
Ref. Screenshot taken by software

By clicking apply a preview of the coin on the built platform with the created supports is illustrated as shown at Fig.10.10.

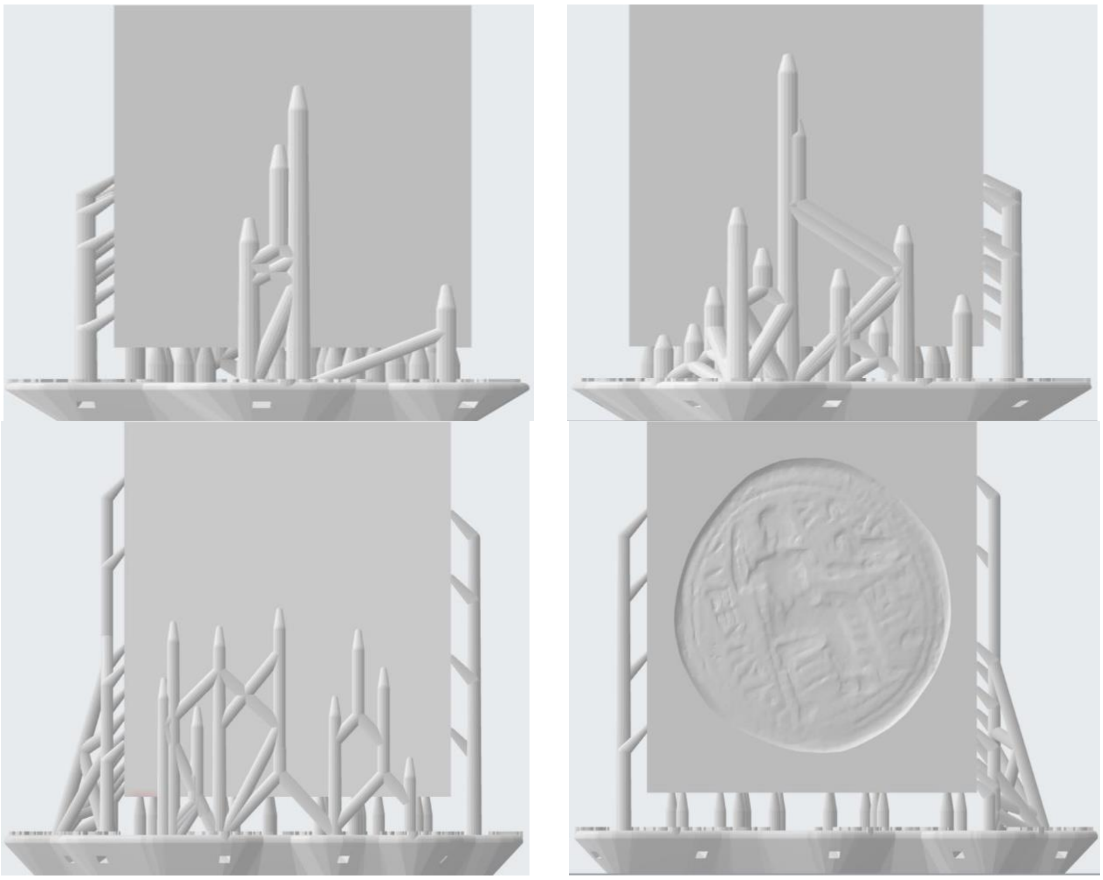


Fig 10.10 The die with the supports structure
Ref. Screenshot taken by software

10.1.3. Positive die preparation

The model is imported in the built platform and repositioned as shown at Fig.10.11

Fig 10.11 Positive Die repositioned on the built platform
Ref. Screenshot taken by software

By enabling the Supports command the coin turns in red color depicting the need of supports as shown at Fig.10.12

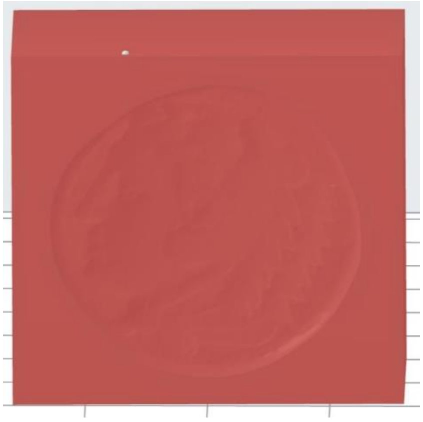


Fig 10.12 Supports command enabled
Ref. Screenshot taken by software

For placing the supports and since we need the surfaces untouched those will be placed at the circumference of the die. After placing the 1st support the die at this area retrieves its original color meaning that at this area the support is strong enough (Fig.10.13).The support emplacement will be repeated until the die retrieves its initial color as shown at Fig.10.14.

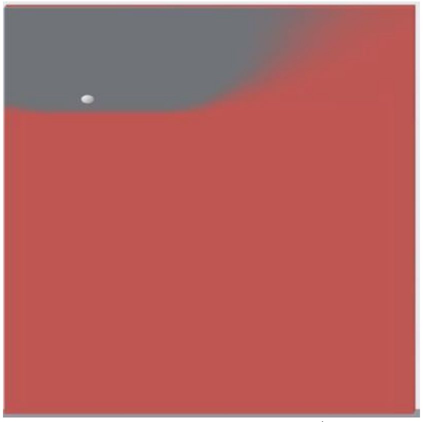
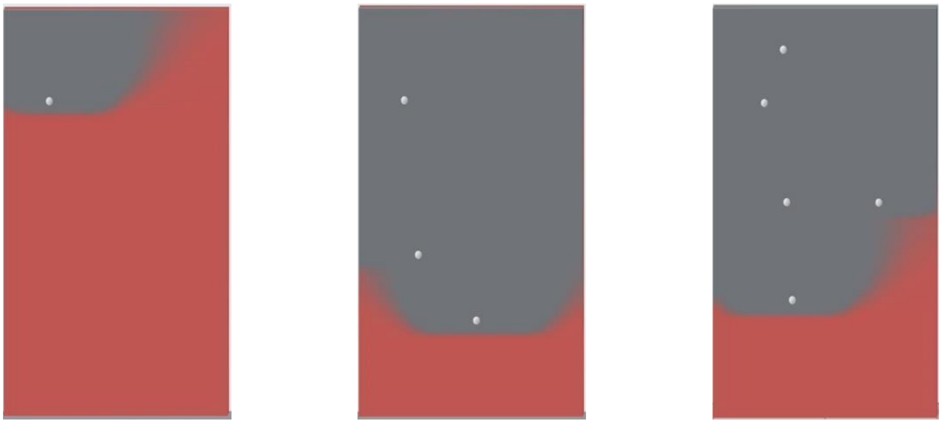


Fig 10.13 Emplacement of 1st support
Ref. Screenshot taken by software



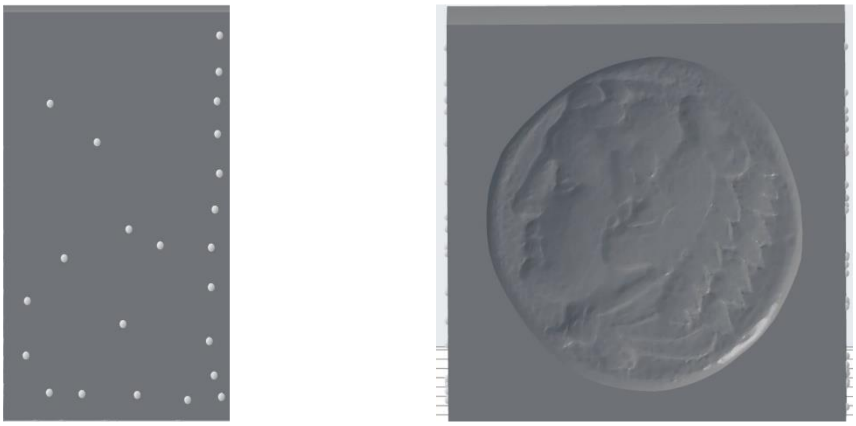


Fig 10.14 Emplacement of the needed supports for the structure
Ref. Screenshot taken by software

By clicking apply a preview of the coin on the built platform with the created supports is illustrated as shown at Fig.10.15.

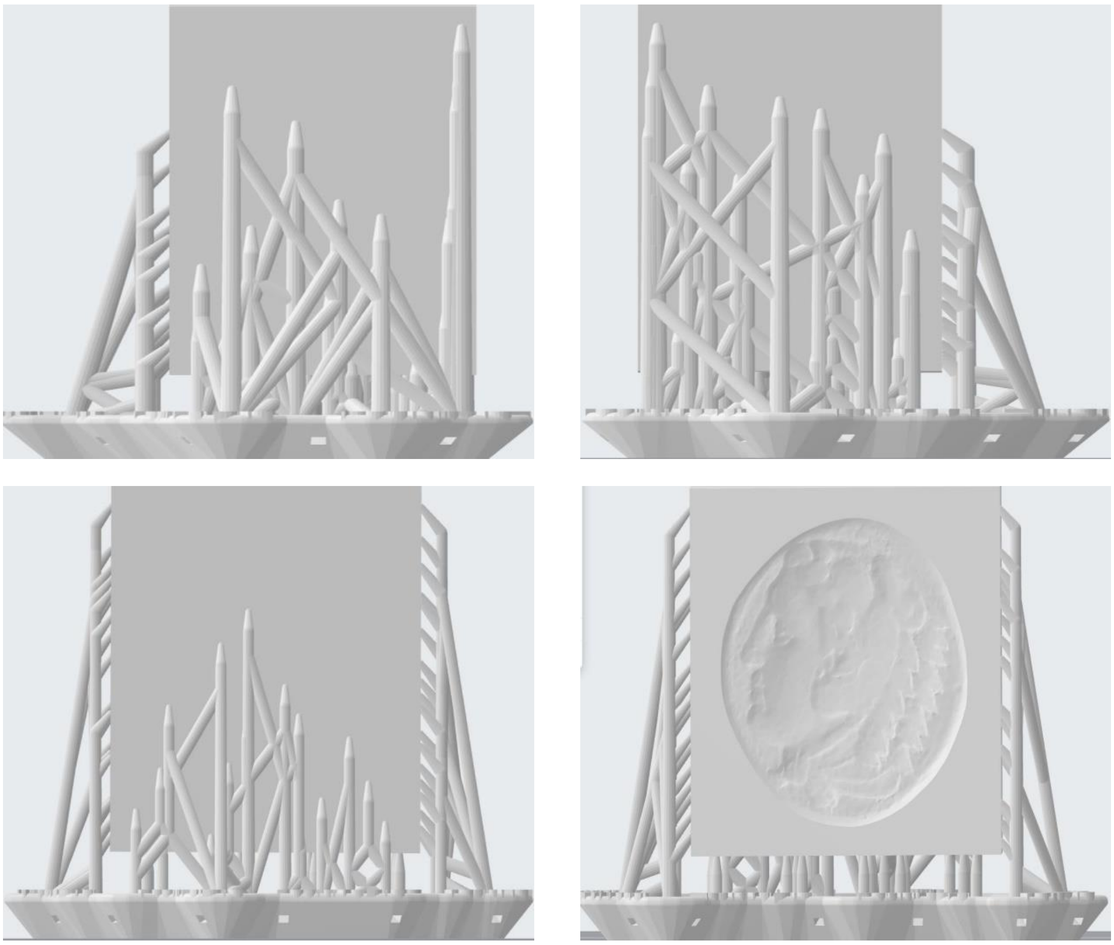


Fig 10.15 The die with the supports structure
Ref. Screenshot taken by software

10.2. Parts preparation with Ultimaker Cura 4.4

10.2.1. Construction parameters

For the coin and dies structure since the main point of interest is printing quality and afterwards the built time some preliminary actions will be applied in order to enhance the process regarding printing quality and furthermore examine the factors which have impact on built time. For that, since Additive Manufacturing machines utilize the layer by layer process for the structure of an object, meaning that the part will be constructed with several 2D sections at x/y axis deposited one upon the other and the thickness of those layers will consist its height (Z axis). The coin will be imported in Cura at its initial position as shown at **Fig.10.16** but will be rotated and placed in a way that the iconography details of the coin and moulds to be constructed in height with the coin views being perpendicular to the built platform as depicted at **Fig.10.17**. The change of orientation results in built time burden but compensates the outcome with much better print quality.

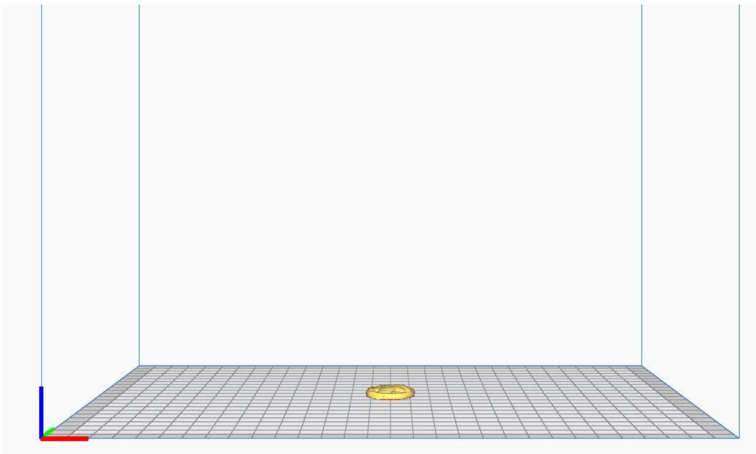


Fig 10.16 Initial Position of the part on the built platform
Ref. Screenshot taken by software

Regarding the inner structure of the parts since the purpose of the dissertation thesis doesn't involve mechanical analysis each part will be subjected to trial iterations for finding the best infill density which results to the best built time with ultimate respect to print quality. So, infill density in relation to layer height will be modified and examined. For the sake of testing infill density will be divided in 4 groups (50-65-80-100%) while the layer height will be grouped in three profiles available by the software as shown at **Fig.10.18**.

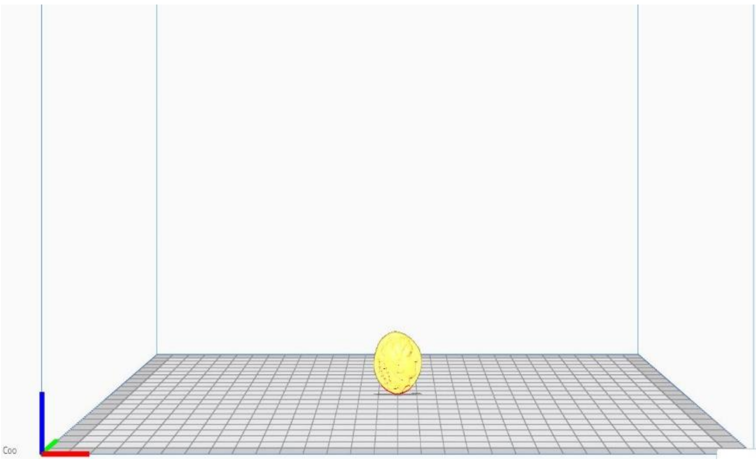


Fig 10.17 Final position of the part on the built platform for obtaining better printing results
Ref. Screenshot taken by software

After the selection of the most suited density which resulted to the best built time for each part a similar preliminary action should be applied before testing each parameter of interest and which will enable the use of variable layer heights during structure, the use of adaptive layers for applying thinner layers at the points of structure which have detailed features whilst use thicker layers at regions which don't need so much attention regarding print quality as shown at **Fig.10.19**.

Fig 10.18 Available profiles by the software
Ref. Screenshot taken by software

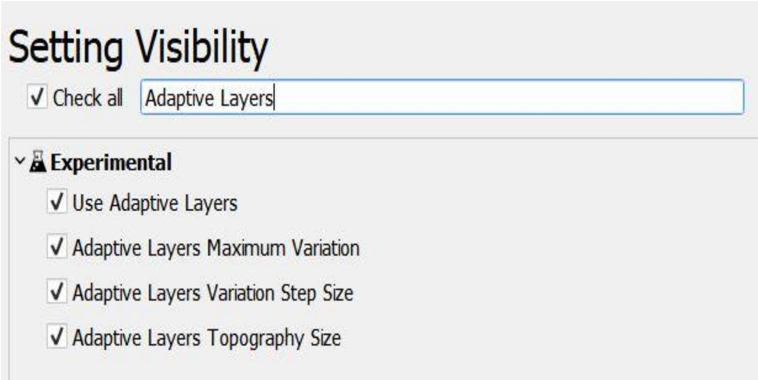


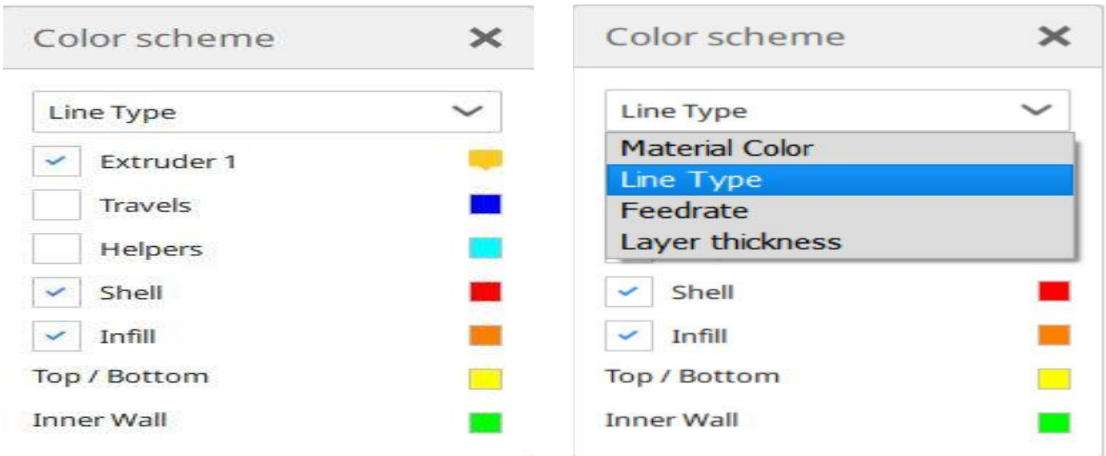
Fig 10.19 Use of Adaptive Layers
Ref. Screenshot taken by software

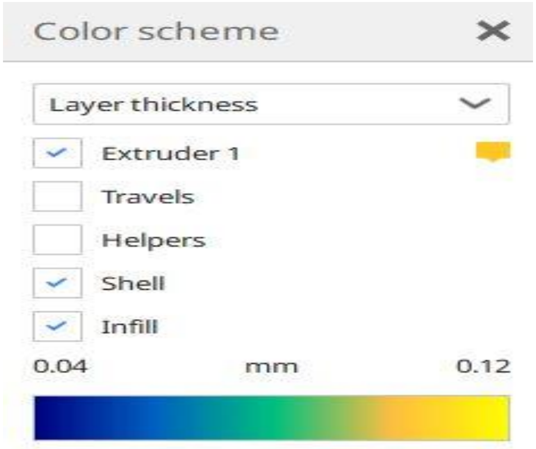
- ❖ The Adaptive Layers Maximum Variation option modifies the layer height difference between the base layer height and the subsequent ones

- ❖ The Adaptive Layers variation step size option enables the control of each new layer in comparison to the previous one.

- ❖ The Adaptive Layers Topography Size option indicates the usage probability of thinner layers during structure. Smaller values will result in higher frequency of thinner layer used while bigger values will make the process to tend in using thicker layers

The modification of "Adaptive Layers" values will show the affect on built time and can be shown as simulation by changing the view mode to Layer View at the Color Scheme Tab as shown at Fig.**10.20**.





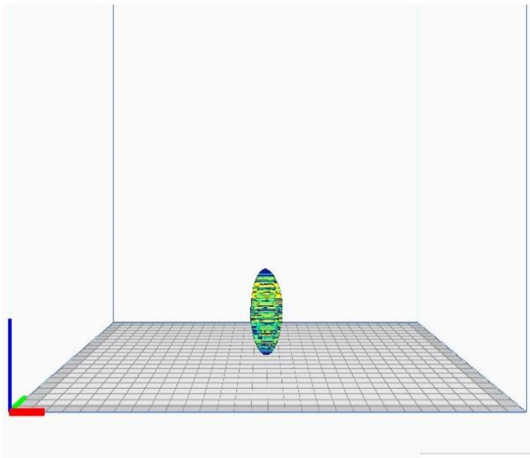


Fig.13 Fig.14

Fig 10.20 Use of Adaptive Layers and simulation
Ref. Screenshot taken by software

10.2.2. FDM coin configuration

For the coin structure the built times will be examined starting by the comparison of 4 infill density groups vs the 3 available profiles as depicted at **Table 10.1** leaving the other settings at default mode except of the "Z hop when retracted" option which results in slightly bigger built time but on the other hand saves unnecessary material from leaking during the travel movement of the nozzle which has negative effect to the final outcome thus to the print quality due to the fact that some post processing actions will be required. The built times are calculated initially with the coin left at its default position at the built platform as shown at Fig.**10.20**. At **Table 10.2** the built times are recalculated with the coin repositioned at the built platform so that the details of the coin to be printed at height as depicted at Fig.16. Subsequently,

Table 10.1 Built times for variable densities and layer thickness with the coin at its initial position on the built platform

	Density			
	50%	**65%**	**80%**	**100%**
Layer Thickness	**Time (min) / Material Consumption (gr) / Number of Layers**			
0.06 mm	**99/2/418**	**110/2/418**	**118/2/418**	**137/2/418**
0.1 mm	**63/2/251**	**68/2/251**	**73/2/251**	**83/1/251**
0.16 mm	**41/2/157**	**44/2/157**	**47/2/157**	**51/2/157**

From Table 1 the clear winner regarding built time is the combination of the 0.16mm Layer Height deposition with 50% density. For Layer Height the 0.1mm layer deposition will be chosen due to the fact that is an adequate value for obtaining good details during printing but furthermore that a similar layer height deposition is chosen at Preform for the construction of the SLA parts.

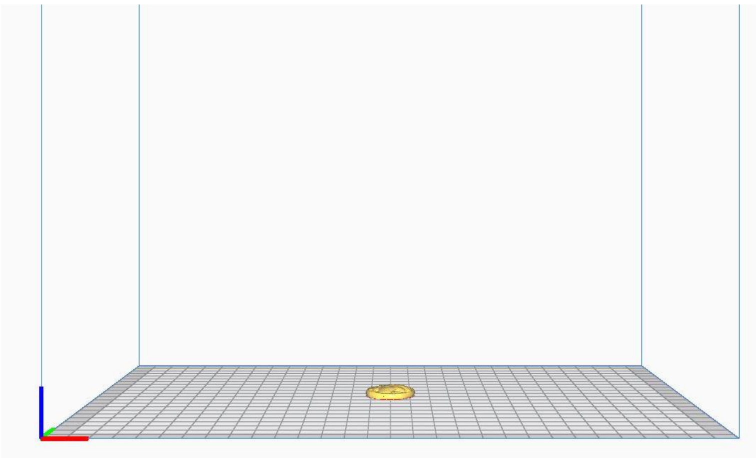


Fig.10.20 Calculations of built times with the coin left at its initial position
Ref. Screenshot taken by software

The estimated built time is 83 min with the structure consisting of 251 layers. The built times are then recalculated by positioning the coin as depicted at Fig.**10.21** and denoted at Table **2**

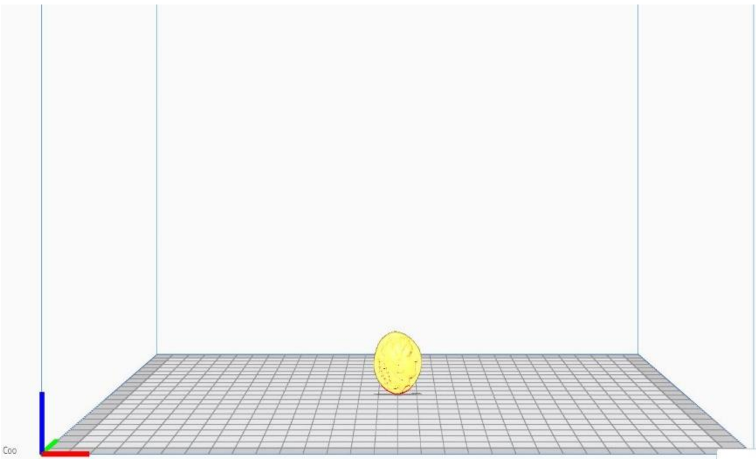


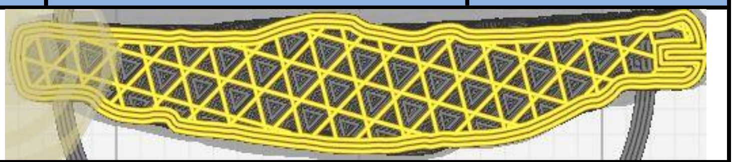
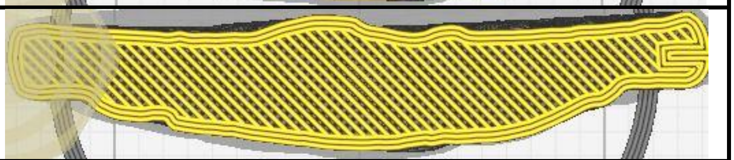
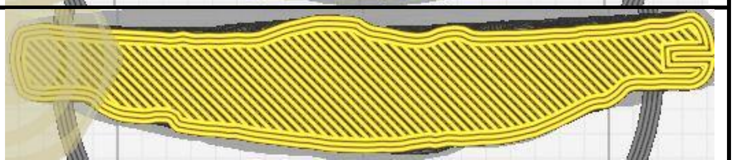
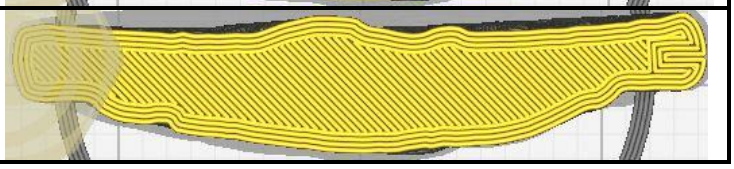
Fig.10.21 Recalculations of built times with the coin rotated and positioned at its final position on the built platform
Ref. Screenshot taken by software

Table 10.2 Built times for variable densities and layer thickness with the coin at its final position on the built platform

	Density			
	50%	65%	80%	100%
Layer Thickness	Time (min) Material Consumption (gr) / Number of Layers			
0.06 mm	109 /2/ 418	116 /2/ 418	125 /2/ 418	146 /2/ 418
0.1 mm	68 /2/ 251	72 /2/ 251	72 /2/ 251	88 /2/ 251
0.16 mm	46 /2/ 157	47 /2/ 157	5 /2/ 157	55 /2/ 157

The results from both Table 1 and 2 depict that the built time is strongly associated with infill density. A more solid part results at higher built times. Even though the infill density is a burden for construction time the coin's infill density is chosen to be 100% meaning the structure of a total solid part since the built up volume is small as shown at Table 10.3. For the mould procedure the affect of infill density will be much more obvious regarding built times. So the estimated built time for the coin is 88 min consisting of 251 layers. The infill pattern has to do with the structural grid and by iteration process we observed that no time difference occurred so the infill pattern will be left at default thus the creation of lines infill pattern which is utilized for quick 2D infill.

Table 10.3 Illustrated infill pattern for four groups of density

Infill Density	Top view at 50% of construction process
50%	
65%	
80%	
100%	

The modified settings will be kept as base settings for further investigation. The next factor that plays crucial role for the construction of the coin has to do with the walls that will be built at each layer. The number of walls during print in comparison to infill density are two inversely functions, meaning that by increment of the walls to be constructed the remaining area for infill will be less and vice versa. Initially the default value for the walls to be constructed is three as shown at Fig.10.22. At Table 10.4 the affect of wall lines number to the built time is presented. The iteration will take place at a scale from three to ten dividing the iteration at four groups in order to find the most appropriate built time.

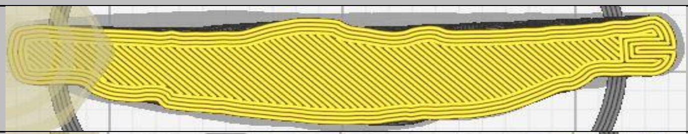
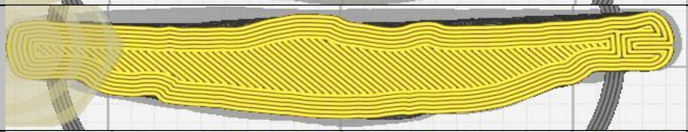
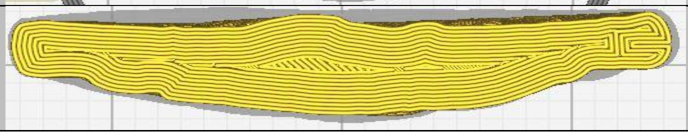
Number of Walls	Top View at 50 % of construction process	Built Time (min)
3		73
5		69
10		73

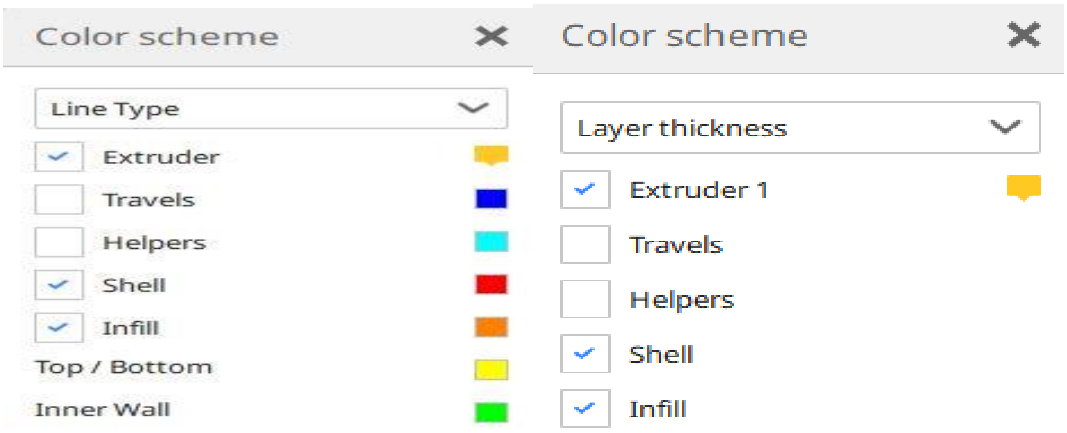
Fig.10.22 Default Wall Line Count Value
Ref. Screenshot taken by software

From Table 10.4 we see that the built time remains unaffected as much as the wall line count increases, so the wall line counts for the coin and the dies will be left at its default value as show at Fig 10.22 . So for the purpose of testing the rest factors influencing print quality and built time will be examined having as base settings the layer height, the density which derived by the iteration process so far. The next factor that has impact on built time as mentioned already is the Adaptive Layers option. When the option is enabled modification of settings regarding layer thickness at points of interest can be applied permitting the software to apply different layer thickness depended on the area to be built as mentioned above (Fig.10.23). For the structure of the coin with the layer height and density already chosen the settings will be subjected in trial iterations in order to find the most suitable variables of layer thickness that compensate the built time but at the same time preserve or improve print quality as shown at Table 10.5.

Table 10.5 Built times for "Adaptive Layers" through trial iteration with base settings Layer Height 0.1mm -Density 100% and number of wall lines 10

	Default Values	Iter. 1	Iter. 2	Iter. 3	Iter. 4	Iter. 5	Iter. 6	Iter. 7	Iter. 8	Iter. 9	Iter. 10
Adaptive Layers max. Variation (mm)	**0.2**	**0.2**	**0.2**	**0.3**	**0.4**	**0.5**	**0.8**	**1**	**0.2**	**0.2**	**0.2**
Adaptive Layers Variation Step Size (mm)	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.05**	**0.08**	**0.1**
Adaptive Layers Topography Size (mm)	**0.1**	**0.2**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**
Time (min)	**195**	**103**	**83**	**83**	**83**	**83**	**83**	**83**	**82**	**80**	**72**

From Table 10.5 we see that all the variables were modified so that the best built time to be obtained. By the default values of "Adaptive Layers" option the resulted time increased dramatically (195 from 88 min).



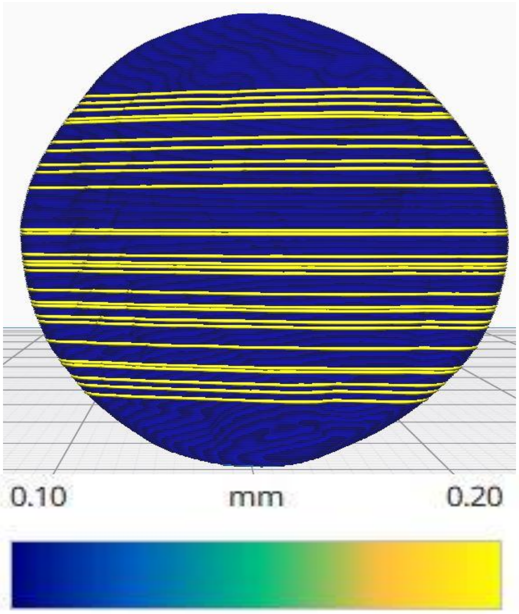


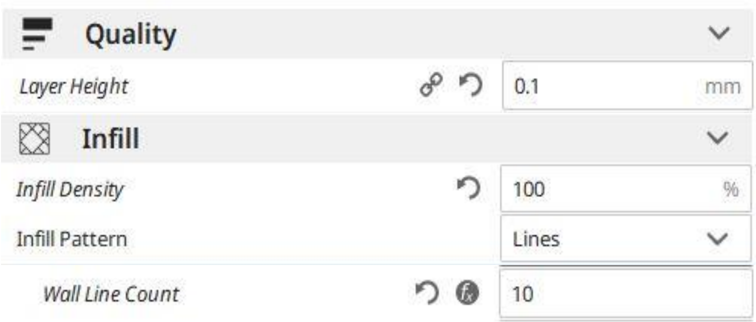
Fig 10.23 Depiction of Adaptive Layers utilization
Ref. Screenshot taken by software

After several modifications of the command values the best built time derives from iteration 10 which results at 11 minutes saving compared to the built time before the enablement of Adaptive Layers (72 from 88 min). The tolerance for the “Adaptive Layers maximum Variation” option has been increased by 0.18mm and resulted to a natural reduction of deposited layers needed for the structure of the coin (189 from 251).The “Adaptive Layers Variation Step Size” value was also set to 0.1mm instead of its initial 0.02mm and the “Adaptive Layers Topography Size” increased by 0.2 mm(0.3 instead of 0.1 mm).With layer height, density and use of Adaptive layers optimally configured the last trial iteration procedure has to do with print speed which is a significant factor regarding print quality and built time. Since the point of interest for the dissertation thesis is focused at the outer surfaces of the coin and imprints of the moulds the print speed settings will be modified accordingly as depicted at Table 10.6. For the iteration the maximum values of Creality CR10-mini will be used as reference units, and will be modified with respect to print quality for identifying the optimal speed settings with potential better built time. Since we are focusing on the outer wall surfaces for the coin and the dies the modification will be done focusing on improving the outer wall print quality by reducing the default values and by increasing the values related to the inner structure of the parts since it won't have any effect during deviation analysis.

Table 10.6 Built times for print speed settings modification with given base settings Layer Height 0.1mm-Density 100%-Adaptive Layers customization

	Default Values	Iter.1	Iter.2	Iter.3	Iter.4	Iter.5	Max.values for Creality CR10-mini (mm/s)
Print Speed (mm/s)	**50**	**50**	**50**	**50**	**45**	**45**	**150**
Infill Speed (mm/s)	**50**	**100**	**125**	**150**	**150**	**150**	**150**
Outer Wall Speed (mm/s)	**25**	**25**	**25**	**25**	**20**	**15**	**150**
Inner Wall Speed (mm/s)	**25**	**50**	**100**	**150**	**150**	**150**	**150**
Built Time (min)	**83**	**77**	**77**	**77**	**81**	**83**	

At Table 10.6 we observe that the best built times derives by the increment of the infill speed settings (Iter.1-2-3).Taking into consideration though the eventual purpose of improving print quality the optimal settings are chosen to be those deriving from Iteration 5. Although the built time is not affected by the settings modification the values for the overall print speed and outer wall speed were slightly reduced which will have a positive impact on print quality. The final settings for the coin gcode creation are presented at Fig.10.24.



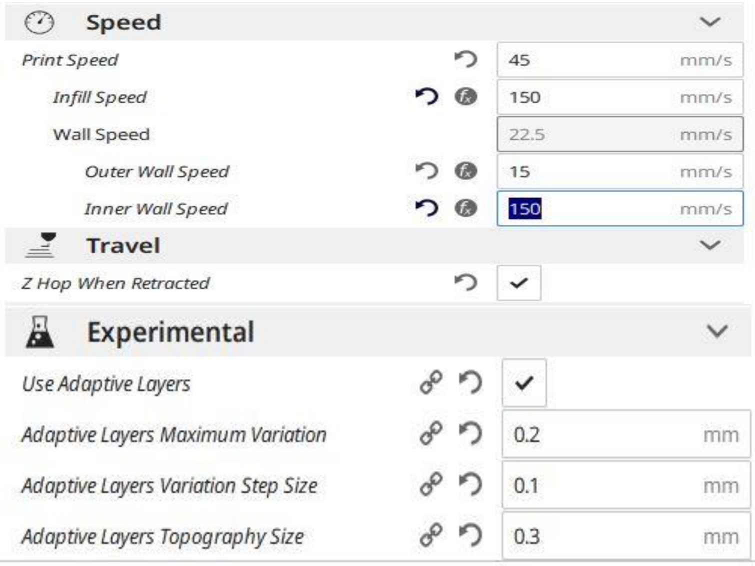


Fig 10.24 The final coin settings modification
Ref. Screenshot taken by software

The construction preview and the final outcome at Front view is depicted at Fig.**10.25**

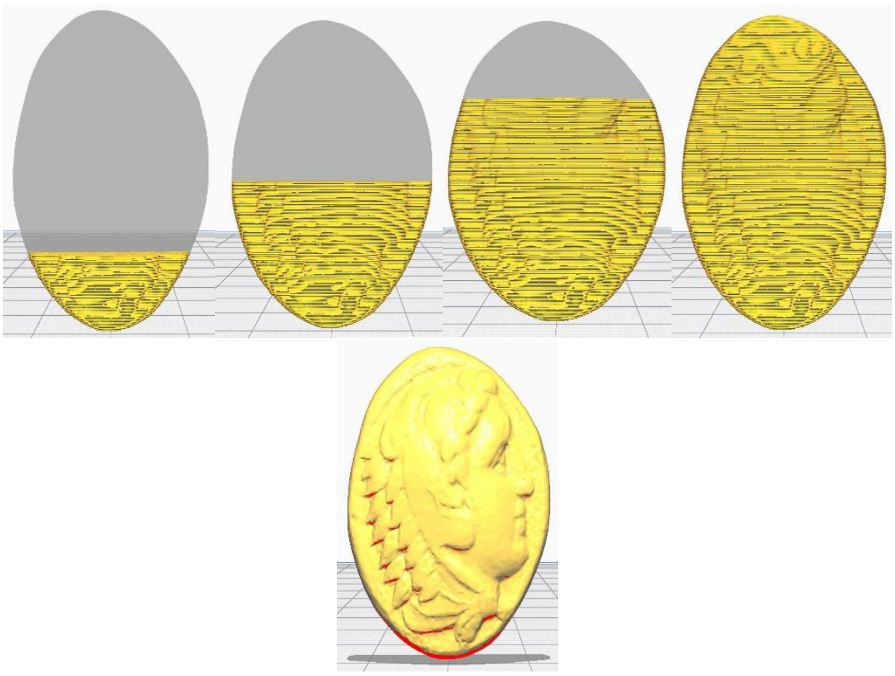


Fig 10.25 Construction procedure and final outcome of the coin
Ref. Screenshot taken by software

The same procedure will be conducted for the configuration of the settings regarding the positive and negative die.

10.2.3. FDM positive die configuration

The positive die will be imported in Cura at its initial position as shown at Fig.10.26 but will be rotated and placed in a way that the iconography details of the die to be constructed in height with the imprinted iconography being perpendicular to the built platform (Fig.10.27).The change of orientation results in built time burden but compensates the outcome with much better print quality. With the die reoriented and repositioned the initial estimated built time with the default values is 11 and 12 min. All the iterations that will take place will be held with a total solid part meaning that an infill density of 100% will be used as an initial setting for the sake of testing and will be examined later on for optimization.

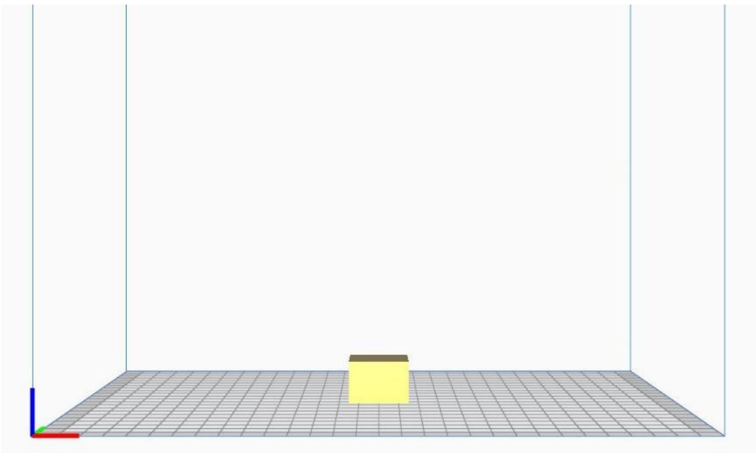


Fig.10.26 The Positive die at its initial position
Ref. Screenshot taken by software

Also a layer height of 0.1mm will be utilized which is an adequate layer height for achieving good print quality results but furthermore the same layer height will be used for the construction of the SLA positive die. Another modification occurred for the iterations is the enablement of the “Z hop when retracted” option which results in slightly bigger built time but on the other hand saves unnecessary material from leaking during the travel movement of the nozzle which has negative effect to the final outcome thus to the print quality due to the fact that some post processing actions will be required. First the die will be subjected to iterations regarding its print speed settings (outer wall and inner wall speed) since the project aims to depict the difference of outer surfaces using different methods of production.

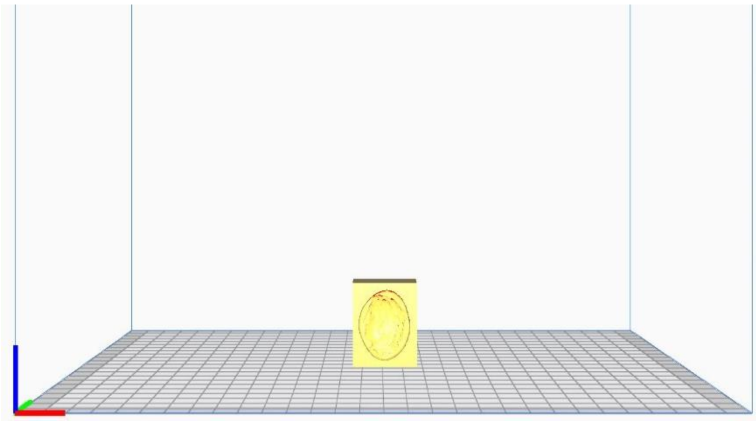


Fig 10.27 The positive die at its final position
Ref. Screenshot taken by software

For this purpose the iteration procedure will mostly focus on reducing the default value of the outer wall speed which refers to the creation of the outer walls of the die the and will be grouped at 6 sectors(1-5-19-15-20-25 mm/s) while the inner wall speed since it has to do with the inner structure of the die the values will be increased during the procedure and will be grouped in 4 sectors (25-50-100-150mm/s).The results of the iteration process are presented at Tables 10.7~10.12.

Table 10.7 Built time calculations based on standard outer wall speed 1mm/s and various inner wall speeds

Iteration	**1**	**2**	**3**	**4**
Outer Wall Speed (mm/s)	1			
Inner Wall Speed (mm/s)	25	50	100	150
Built Time (hrs)	13h 31’	12h 14’	12h 9’	12h 9’

Table 10.8 Built time calculations based on standard outer wall speed 5 mm/s and various inner wall speeds

Iteration	1	2	3	4
Outer Wall Speed (mm/s)	5			
Inner Wall Speed (mm/s)	25	50	100	150
Built Time (hrs)	12h 34’	12h 17’	12h 13’	12h 12’

Table 10.9 Built time calculations based on standard outer wall speed 10 mm/s and various inner wall speeds

Iteration	1	2	3	4
Outer Wall Speed (mm/s)	10			
Inner Wall Speed (mm/s)	25	50	100	150
Built Time (hrs)	11h 42’	11h 25’	11h 21’	11h 20’

Table 10.10 Built time calculations based on standard outer wall speed 15 mm/s and various inner wall speeds

Iteration	1	2	3	4
Outer Wall Speed (mm/s)	15			
Inner Wall Speed (mm/s)	25	50	100	150
Built Time (hrs)	11h 25’	11h 8’	11h 3’	11h 3’

Table 10.11 Built time calculations based on standard outer wall speed 20 mm/s and various inner wall speeds

Iteration	1	2	3	4
Outer Wall Speed (mm/s)	20			
Inner Wall Speed (mm/s)	25	50	100	150
Built Time (hrs)	11h 16’	11h	10h 55’	10h 55’

Table 10.12 Built time calculations based on standard outer wall speed 25 mm/s and various inner wall speeds

Iteration	1	2	3	4
Outer Wall Speed (mm/s)	25			
Inner Wall Speed (mm/s)	25	50	100	150
Built Time (hrs)	11h 12’	10h 55’	10h 50’	10h 50’

Conclusions

- From the iteration took place we see that the built time at every outer wall sector isn’t affected as shown at all the tables by increment of the infill speed beyond 100 mm/s
- The best outer wall speed factor that satisfies the built time is the one with the outer wall speed value left at default and by increment of the inner wall speed to 100 mm per second which results at time saving of 22 min.
- The best print quality, as expected, derives from outer wall speed of 1 mm per second and the inner wall speed set at 100 mm/s but this also results to be time consuming process.(from 11h and 12’ to 12h 9’)
- The best built time with respect to the aim of improving quality is achieved by an outer wall speed of 20 mm per second and results at a time saving of 17 min regarding the printing process.

The second best built time derives by the use of outer wall speed of 15 mm per second but at the same time saves 9 min of printing process and these are the qualified print speed settings deriving from Table .With the layer height defined and the best printing values designated we managed to improve quality print by reducing the outer wall speed by 10 mm/s, a crucial factor for quality improvement and at the same time fulfilled the requirements regarding the subsequent aim of reducing built time by 9 min. Now, the next factor who’ll deliberately examined after the speed settings modification is the infill density. As shown with the optimal settings applied for a total solid part the built time was slightly reduced but the biggest gain from the procedure was the print quality improvement. Since we mostly care about the outer surfaces and the number of walls to be constructed is left untouched as shown at Table 10.13 infill density can result at much better built times. At Table 10.14 the sequence of iterations regarding the same four groups of infill density used for the coin construction is described. (Shorthand for Layer Height: L.H., Outer Wall Speed: O.W.S., Infill Wall Speed: I.W.S.).

Table 10.13 Correlation between the number of walls to be constructed and built time

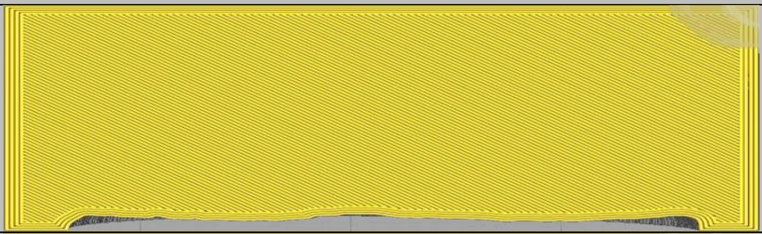
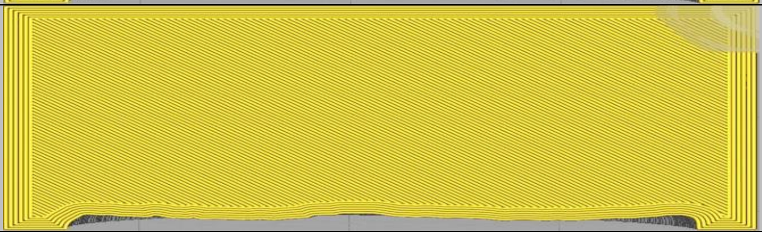
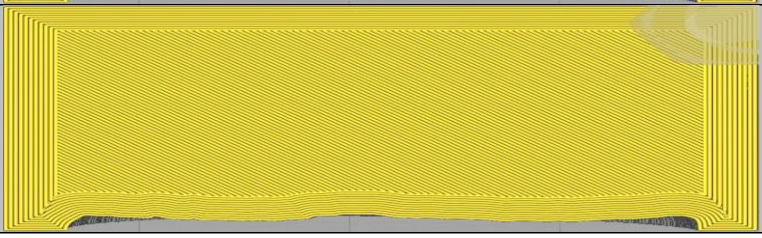
Number of Walls	Top View at 50 % of construction	Built Time (hrs)
3		11h 12'
5		11h 12'
10		11h 12'

Table 10.14 Built time calculations based on four density groups

	Density			
Percentage (%)	100%	80%	65%	50%
Modified layer height-print speed settings	L.H:0.1mm O.W.S. 15mm/s I.W.S 100mm/s			
Built time (Hrs)	11h 3'	6h 36'	5h 49'	5h 6'

From Table **10.14** we see that the built time is strongly associated with infill density. Since the point of interest is located on the outer surfaces the chosen density will be set to 50% which results at construction time saving of 5h 57 min (from 11h 3' to 5h 6'). With designation of the infill density the last thing to be done for further investigating the prospects of improving quality is the use of the forementioned "Adaptive Layers". The iteration process will take place with the optimal settings calculated so far applied and with use of thinner or thicker layers at areas of interest will be examined as shown at Fig.10.28. By enabling the "Adaptive Layer' command, the estimated built time is 26 min more compared to the built time with the default settings (from 5h 6' to 5h 42') as shown at Fig. 10.29

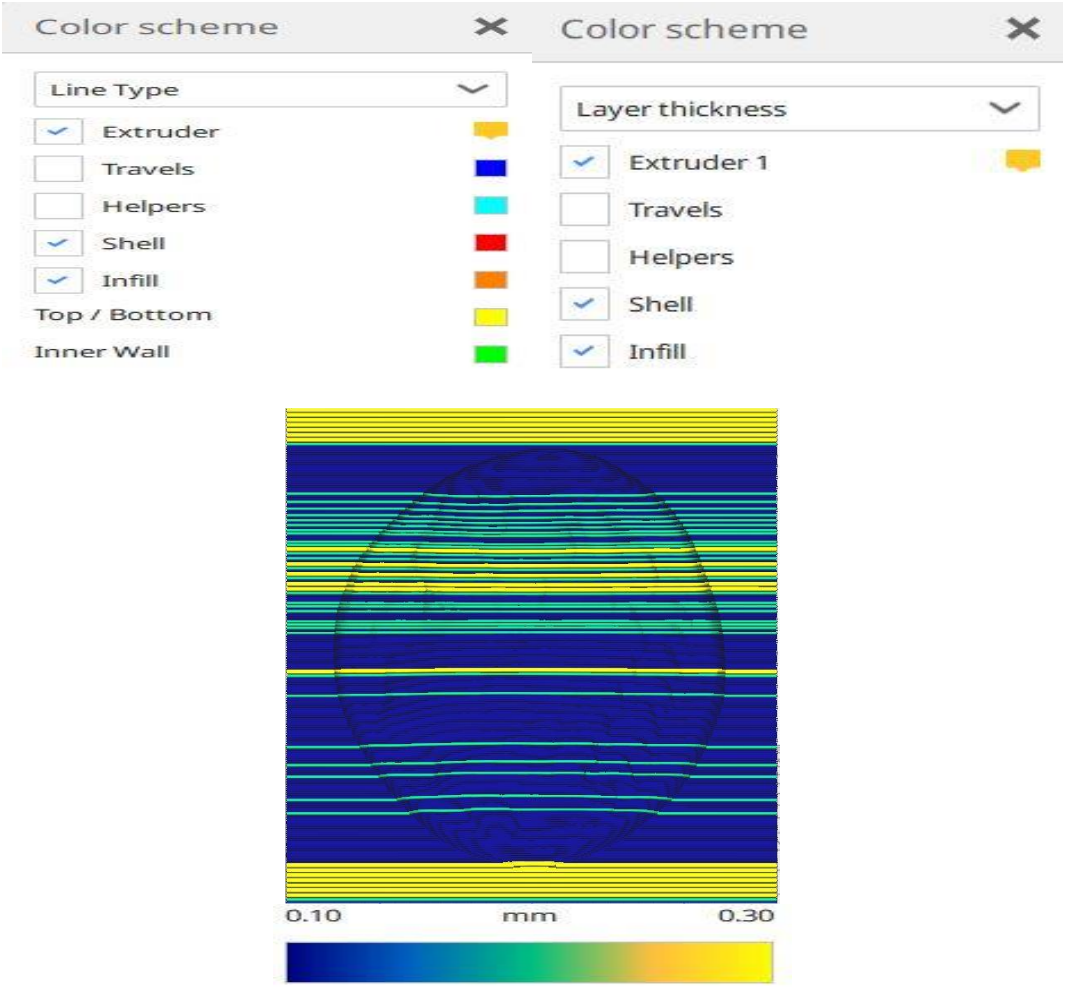


Fig 10.28 Depiction of Adaptive Layers utilization
Ref. Screenshot taken by software

For the iteration process some shorthand will be used:

Adaptive Layers Maximum Variation: ALMV

Adaptive Layer Variation Step Size: ALVSS

Adaptive Layer Topography Size: ALTS

The iteration process will take place by modifying the initial values of the command as shown at **Fig.10.30.** by first modifying the ALMV value keeping the other two at default and subsequently the ALVSS will be modified by keeping the best value of ALMV as base setting and the ALTS at default value. The last iteration will be held with the best values of ALMV and ALVSS as base settings and the ALTS options will be modified accordingly.

Fig 10.29 Use of Adaptive Layers command enablement
Ref. Screenshot taken by software

Fig 10.30 Initial values for Adaptive Layers
Ref. Screenshot taken by software

At Table **10.15** the grouping of values for every factor of Adaptive layers command is depicted.

Table 10.15 Grouping of Adaptive Layers command values

Adaptive Layer Maximum Variation (ALMV) (mm)	0.04	0.03	0.02	0.01			
Adaptive Layers Variation Step Size (ALVSS) (mm)	0.04	0.05	0.06	0.07	0.08	0.09	0.1
Adaptive Layers Topography Size (ALTS) (mm)	0.2	0.1	0.3	0.6	1.2	1.5	

Based on the grouping shown at Table 10.15 the iteration process will take place and the results of the process are presented at Table 10.16.

Table 10.16 Built time calculation based on various ALMV values with ALVSS-ALTS values at default

	Default Values	**Iteration 1**	**Iteration 2**	**Iteration 3**
ALMV (mm)	**0.04**	**0.03**	**0.02**	**0.01**
ALVSS	**0.04**	**0.04**		

(mm)				
ALTS (mm)	0.2	0.2		
Built Time (Hrs)	5h 42’	4h 53’	5h 16’	4h 42’

From Table 10.16 we see that the best resulting built time for modified ALMV is iteration 3 which results at a time saving of 1 hour compared to the initial built time an d will be chosen as base setting for the next iteration as shown at Table 10.17.

Table 10.17 Built time calculation based on various ALVSS values with ALMV-ALTS values at default

	Default Values	Iteration 1	Iteration 2	Iteration 3	Iteration 4	Iteration 6	Iteration 7
ALMV	0.01	0.01					
ALVSS	0.04	0.05	0.06	0.07	0.08	0.09	0.1
ALTS	0.2	0.2					
Built Time (hrs)	4h 42’	4h 42’	4h 42’	4h 42’	4h 42’	4h 42’	4h 42’

From Table 10.17 we see that the modification of the ALVSS value doesn’t affect the built time at all so it will be left at the default value for the next iteration. At Table 10.18 the iterations occurred by leaving at default values the ALMV and ALVSS values and modifying the ALTS values us depicted.

Table 10.18 Built time calculation based on various ALTS values with ALMV-ALVSS values at default

	Default Values	Iteration 1	Iteration 2	Iteration 3	Iteration 4	Iteration 5
ALMV (mm)	0.01	0.01				
ALVSS (mm)	0.04	0.04				
ALTS (mm)	0.2	0.1	0.3	0.6	1.2	1.5
Built time (hrs)	4h 42’	4h 42’	4h 42’	4h 42’	4h 42’	4h 42’

From Table 10.18 we see that the modification of the ALTS value doesn't affect the built time at all so its initial value will be applied. The modified settings for the positive die construction are depicted at Fig.10.31 with the other settings left at default values as they were judged to be adequate for the printing process. The same procedure for the selection of the optimal settings regarding the construction of the negative die will follow.

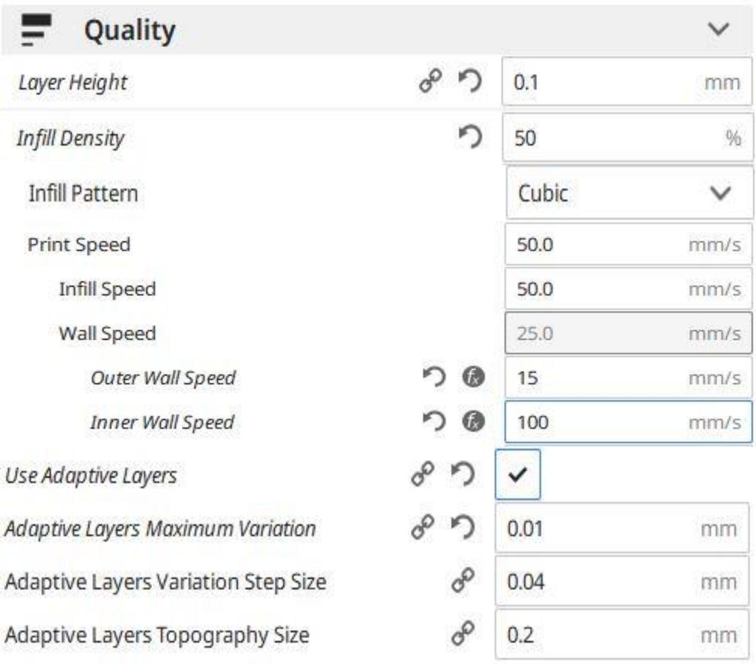


Fig 10.31 Final Settings for the Positive die
Ref. Screenshot taken by software

The construction preview and the final outcome at Front view is depicted at Fig.10.32

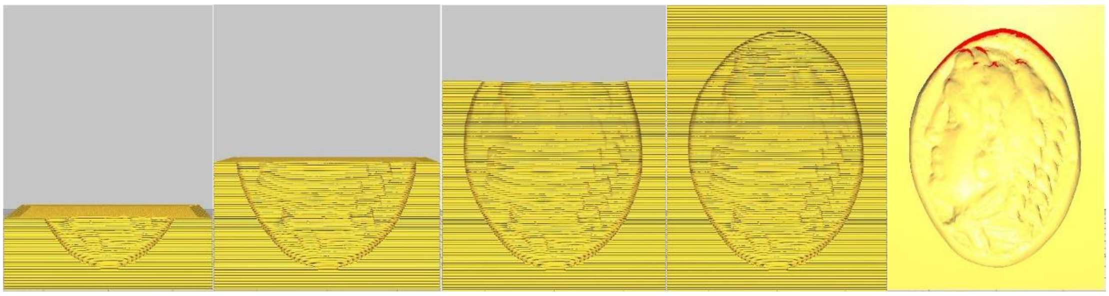


Fig 10.32 Construction procedure and final outcome of the positive die
Ref. Screenshot taken by software

10.2.4. FDM negative die configuration

The negative die is imported in Cura at its initial position as shown at Fig.**10.33** but will be rotated and placed in a way that the iconography details of the die to be constructed in height with the imprinted iconography being perpendicular to the built platform. The change of orientation results in built time burden but compensates the outcome with much better print quality. With the die reoriented and repositioned the initial estimated built time with the default values is 11 and 31 min. All the iterations that will take place at first will be held with a total solid part meaning that an infill density of 100% will be used as an initial setting for the sake of testing and will be examined later on for optimization. Also a layer height of 0.1mm will be utilized which is an adequate layer height for achieving good print quality results but furthermore the same layer height will be used for the construction of the SLA negative die. Another modification occurred for the iterations is the enablement of the “Z hop when retracted” option which results in slightly bigger built time but on the other hand saves unnecessary material from leaking during the travel movement of the nozzle which has negative effect to the final outcome thus to the print quality due to the fact that some post processing actions will be required. First the die will be subjected to iterations regarding its print speed settings (outer wall and inner wall speed) since the project aims to depict the difference of outer surfaces using different methods of production. For this purpose the iteration procedure will mostly focus on reducing the default value of the outer wall speed which refers to the creation of the outer walls of the die the and will be grouped at 6 sectors(1-5-19-15-20-25 mm/s) while the inner wall speed since it has to do with the inner structure of the die the values will be increased during the procedure and will be grouped in 4 sectors(25-50-100-150 mm/s).The results of the iteration process are presented at Tables 10.19~10.24.

Table 10.19 Built time calculations based on standard outer wall speed 1mm/s and variable inner wall speeds

Iteration	**1**	**2**	**3**	**4**
Outer Wall Speed (mm/s)	**1**			
Inner Wall Speed (mm/s)	**25**	**50**	**100**	**150**
Built Time (hrs)	**20h 02’**	**19h 44’**	**19h 40’**	**19h 40’**

Table 10.20 Built time calculations based on standard outer wall speed 5 mm/s and various inner wall speeds

Iteration	**1**	**2**	**3**	**4**
Outer Wall Speed (mm/s)	**5**			
Inner Wall Speed (mm/s)	**25**	**50**	**100**	**150**
Built Time (hrs)	**12h 56’**	**12h 38’**	**12h 33’**	**12h 33’**

Table 10.21 Built time calculations based on standard outer wall speed 10 mm/s and various inner wall speeds

Iteration	1	2	3	4
Outer Wall Speed (mm/s)	10			
Inner Wall Speed (mm/s)	25	50	100	150
Built Time (hrs)	12h 03’	11h 45’	11h 40’	11h 40’

Table 10.22 Built time calculations based on standard outer wall speed 15 mm/s and various inner wall speeds

Iteration	1	2	3	4
Outer Wall Speed (mm/s)	15			
Inner Wall Speed (mm/s)	25	50	100	150
Built Time (hrs)	11h 45’	11h 27’	11h 23’	11h 23’

Table 10.23 Built time calculations based on standard outer wall speed 20 mm/s and various inner wall speeds

Iteration	1	2	3	4
Outer Wall Speed (mm/s)	20			
Inner Wall Speed (mm/s)	25	50	100	150
Built Time (hrs)	11h 36’	11h 19’	11h 14’	11h 14’

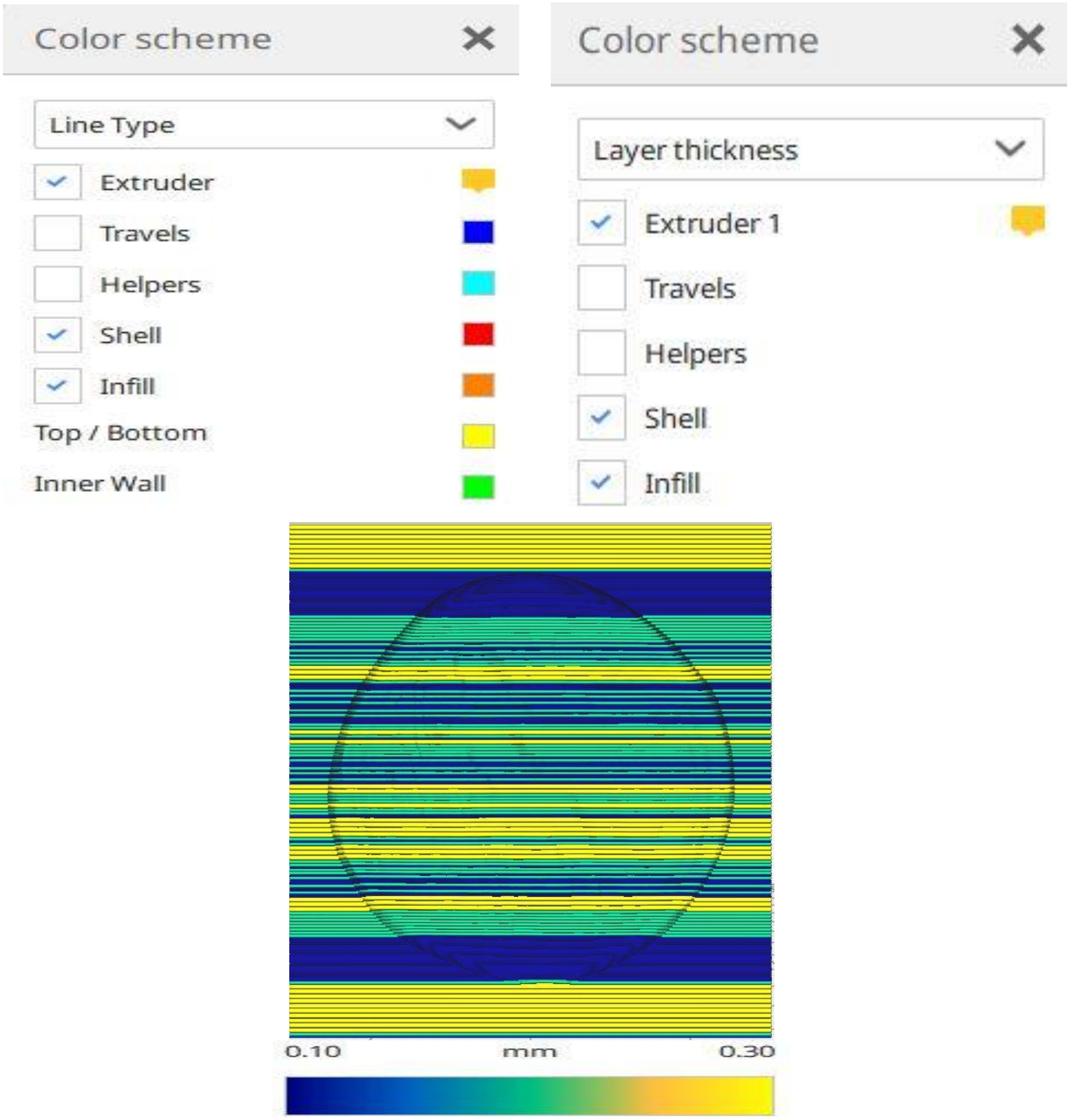
Table 10.24 Built time calculations based on standard outer wall speed 25 mm/s and various inner wall speeds

Iteration	1	2	3	4
Outer Wall Speed (mm/s)	25			
Inner Wall Speed (mm/s)	25	50	100	150
Built Time (hrs)	11h 31’	11h 14’	11h 9’	11h 9’

Conclusions

- From the iteration took place we see that the built time at every outer wall sector isn't affected as shown at all the tables by increment of the infill speed beyond 100 mm/s
- The best outer wall speed factor that satisfies the built time is the one with the outer wall speed value left at default and by increment of the inner wall speed to 100 mm per second which results at time saving of 22 min.
- The best print quality, as expected, derives from outer wall speed of 1 mm per second and the inner wall speed set at 100 mm/s but this also results to be time consuming process.(from 11h 31' to 12h 9')
- The best built time with respect to the aim of improving quality is achieved by an outer wall speed of 20 mm per second and results at a time saving of 17 min regarding the printing process.
- The second best built time derives by the use of outer wall speed of 15 mm per second but at the same time saves 8 min of printing process and these are the qualified print speed settings deriving from Table **10.22** highlighted on yellow.
- With the layer height defined and the best printing values designated we managed to improve quality print by reducing the outer wall speed by 10 mm/s, a crucial factor for quality improvement and at the same time fulfilled the requirements regarding the subsequent aim of reducing built time by 8 min. Now, the next factor who'll deliberately examined after the speed settings modification is the infill density. As shown with the optimal settings applied for a total solid part the built time was slightly reduced but the biggest gain from the procedure was the print quality improvement. Since we mostly care about the outer surfaces and the number of walls to be constructed is left untouched as shown at **Fig**. Infill density can result at much better

built times. At Table the sequence of iterations regarding the same four groups of infill density used for the coin construction will be utilized.



For the iteration process some shorthand will be used:

Adaptive Layers Maximum Variation: ALMV

Adaptive Layer Variation Step Size: ALVSS

Adaptive Layer Topography Size: ALTS

Table 25 Correlation between the number of walls to be constructed and built time

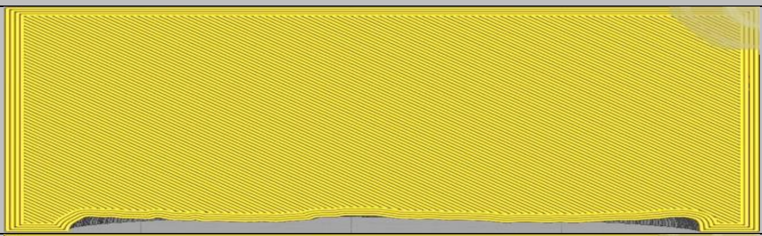
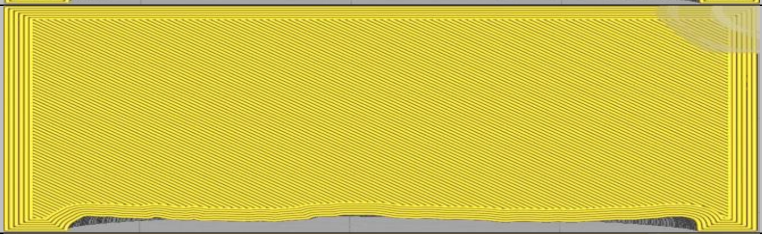
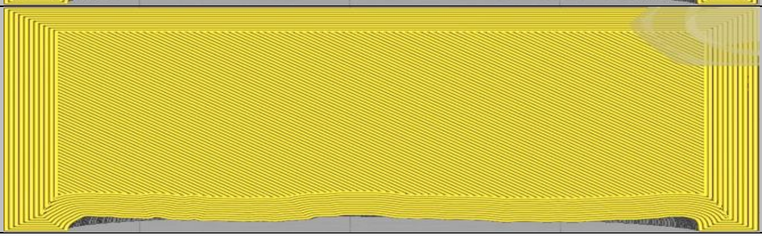
Number of Walls		**Built Time (hrs)**
3		**11h 31’**
5		11h 31’
10		11h 31’

Table 10.26 Built times with various values of infill density

	Density			
Percentage (%)	**100%**	**80%**	**65%**	**50%**
Modified layer height-print speed settings	**L.H:0.1mm O.W.S. 15mm/s I.W.S 100mm/s**			
Built time (Hrs)	**11h 31’**	**6h 48’**	**5h 58’**	**5h 9’**

From Table **10.26** we see that the built time is strongly associated with infill density. Since the point of interest is located on the outer surfaces the chosen density will be set to 50% which results at construction time saving of 6h 22 min (from 11h 31’ to 5h 9’).

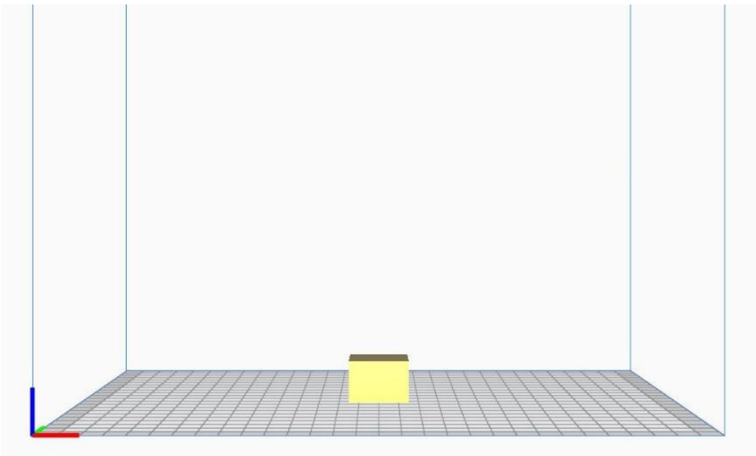


Fig 10.33 The negative die at its initial position
Ref. Screenshot taken by software

With the designation of the infill density complete the factor which will be further investigated regarding the prospects of improving quality is the use of the “Adaptive Layers”. The iteration process will take place with the base settings to be the calculated ones so far and with use of thinner or thicker layers at areas of interest will be examined. By activating the “Adaptive Layer’ option (Fig.10.35) the estimated built time is increased by 26 min (from 5h 9’ to 5h 50’) (Shorthand _Adaptive Layers Maximum Variation: ALMV, (Adaptive Layer Variation Step Size: ALVSS, Adaptive Layer Topography Size: ALTS).

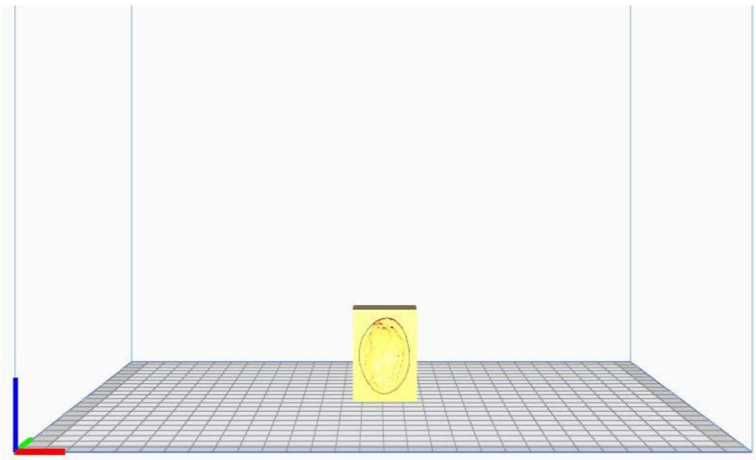


Fig 10.34 The positive die at its final position
Ref. Screenshot taken by software

The iteration process will take place by modifying the initial values of the command as shown at Fig. by first modifying the ALMV value keeping the other two at default and subsequently the ALVSS will be modified by keeping the best value of ALMV as base setting and the ALTS at default value. The last iteration will be held with the best values of ALMV and ALVSS as base settings and the ALTS options will be modified accordingly.

Fig 10.35 Use of Adaptive Layers command enablement

Fig 10.36 Initial values for Adaptive Layers
Ref. Screenshot taken by software

At Table 10.27 the grouping of values for every factor of Adaptive layers command is depicted.

Table 10.27 Grouping of Adaptive Layers command values

Adaptive Layer Maximum Variation (ALMV)	0.04	0.03	0.02	0.01			
Adaptive Layers Variation Step Size (ALVSS)	0.04	0.05	0.06	0.07	0.08	0.09	0.1
Adaptive Layers Topography Size (ALTS)	0.2	0.3	0.4	0.6	1.2	1.5	

Based on the grouping shown at Table 10.27 the iteration process will take place and the results of the process are presented at Table 10.28

Table 10.28 Built time calculation based on various ALMV values with ALVSS-ALTS values at default

	Default Values	Iteration 1	Iteration 2	Iteration 3
ALMV	0.04	0.03	0.02	0.01
ALVSS	0.04	0.04		
ALTS	0.2	0.2		
Built Time (Hrs)	5h 50’	5h 34’	4h 52’	4h 45’

From Table 10.28 we see that the best resulting built time for modified ALMV is iteration 3 which results at a time saving of 1 hour compared to the initial built time and will be chosen as base setting for the next iteration as shown at Table 10.29

Table 29 Built time calculation based on various ALVSS values with ALMV-ALTS values at default

	Default Values	Iteration 1	Iteration 2	Iteration 3	Iteration 4	Iteration 6	Iteration 7
ALMV	0.01	0.01					
ALVSS	0.04	0.05	0.06	0.07	0.08	0.09	0.1
ALTS	0.2	0.2					
Built Time (hrs)	4h 45’	4h 45’	4h 45’	4h 45’	4h 45’	4h 45’	4h 45’

From Table 10.29 we see that the modification of the ALVSS value doesn’t affect the built time at all so it will be left at the default value for the next iteration (Table 10.30).

Table 10.30 Built time calculation based on various ALTS values with ALMV-ALVSS values at default

	Default Values	Iteration 1	Iteration 2	Iteration 3	Iteration 4	Iteration 5
ALMV (mm)	0.01	0.01				
ALVSS (mm)	0.04	0.04				
ALTS (mm)	0.2	0.1	0.3	0.6	1.2	1.5
Built time (hrs)	4h 45’	4h 45’	4h 45’	4h 45’	4h 45’	4h 45’

From Table 10.30 we see that the modification of the ALTS value doesn’t affect the built time at all so its initial value will be applied. The modified settings for the negative die construction are depicted at Fig.10.37 with the other settings left at default values as they were judged to be adequate for the printing process.

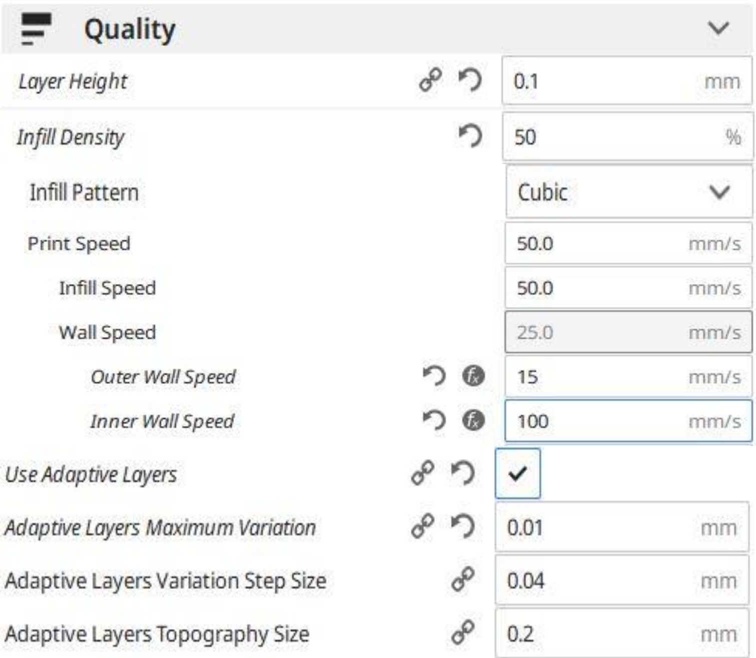


Fig 10.37 Final Settings for the negative die
Ref. Screenshot taken by software

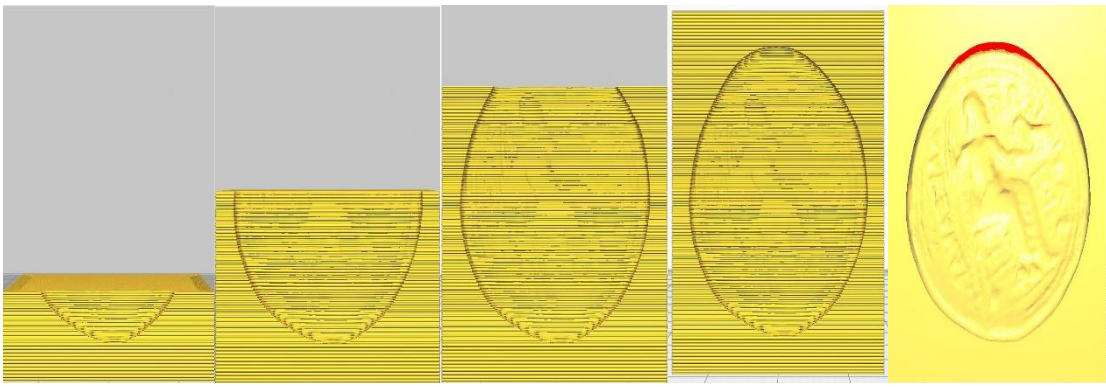


Fig 10.38 Construction procedure and final outcome of the positive die
Ref. Screenshot taken by software

11. STRUCTURE PROCEDURE OF THE COINS AND DIES

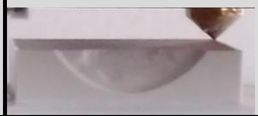
In this chapter a visual representation of the coins and dies will be presented. The FDM coin will be constructed with use of supports due to the fact that the aim is its iconography details to be printed at height so the printed area of the base is too small and there is a strong possibility of failing. The final specifications for the coin and dies are depicted at Table 11.1 while the construction process of the coin and the two dies are depicted at Table 11.2

11.1. FDM coin and dies configuration

Table 11.1 Final customization before printing process

<table>
<tr><th>Part</th><th>Filament used</th><th>Filament Diameter (mm)</th><th>Filament Color</th><th>Printing Temp (ºC)</th><th>Bed Temp. (ºC)</th><th>Use of supports</th></tr>
<tr><td>Coin</td><td rowspan="3">PLA</td><td rowspan="3">1.75</td><td>Bronze</td><td rowspan="3">195</td><td rowspan="3">90</td><td>Yes</td></tr>
<tr><td>Positive Die</td><td rowspan="2">Light Grey</td><td>No</td></tr>
<tr><td>Negative Die</td><td>No</td></tr>
</table>

Table 11.2 FDM Construction procedure

	Construction process (%)			
	25	50	75	100
Coin				
Positive Die				
Negativ e Die				

11.2. SLA coin and dies

The coin and dies after the structure is complete and they detached from the built platform they should be subjected in post processing so that the final parts to be obtained. Each part will be left in an isopropyl bath (Fig.11.1) and after that the supports for the coin will be trimmed away (Fig.11.2-11.3). The structured dies are presented at Fig.11.4

Fig 11.1 The coin and the dies are placed in Isopropyl bath

Fig 11.2 SLA Coin with supports after Isopropyl bath (Front and Back view)

Fig 11.3 SLA Coin with no supports after Isopropyl Bath (Front and Back view)

Fig 11.4 Positive and Negative SLA dies after Isopropyl Bath

11.3. Clay coin

The coin made out of clay was made by the associate mould craftsman of Aristotle University. The coin was constructed with clay as the constructed material and at two different colors (Fig.11.5). For replicating the coin the mould should be made out of plaster in order to be separated from the coin. The plaster coin is presented at Fig.11.6.

Fig. 11.5 The clay coins and the original

Fig 11.6 Clay Coin

12. RE-SCAN AND RE-MANIPULATION OF THE COINS AND MOULDS WITH USE OF NEXTENGINE SCAN STUDIO

With the scanning process we attained the data of each coin and die. Now, the data will be imported once more in Next Engine Scan Studio and manipulated in order to obtain the final STL files which will be used for deviation analysis. Due to the large number of parts to be manipulated the procedure will take place for all the parts by the following order:

- Trim
- Align
- Fuse
- Export to *stl format

The procedure for the FDM coin will be fully described while the others will be conducted with the same steps followed.

12.1. FDM coin

The scanned data of the coin are imported in Scanstudio as shown at Fig.12.1

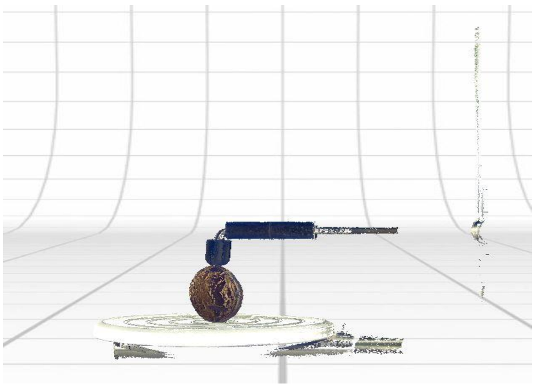


Fig 12.1 Import the coin in Scanstudio
Ref. Screenshot taken by software

The laser during scanning obtained besides the needed data (coin surfaces) unwanted portions of data also such as the bed platform of the scanner.For trimming these portions and lighten the file size the trim command will be activated and the trim selection at the subtabs will be enabled.The unwanted portions are marked and appeared in red color as shown at Fig.12.2

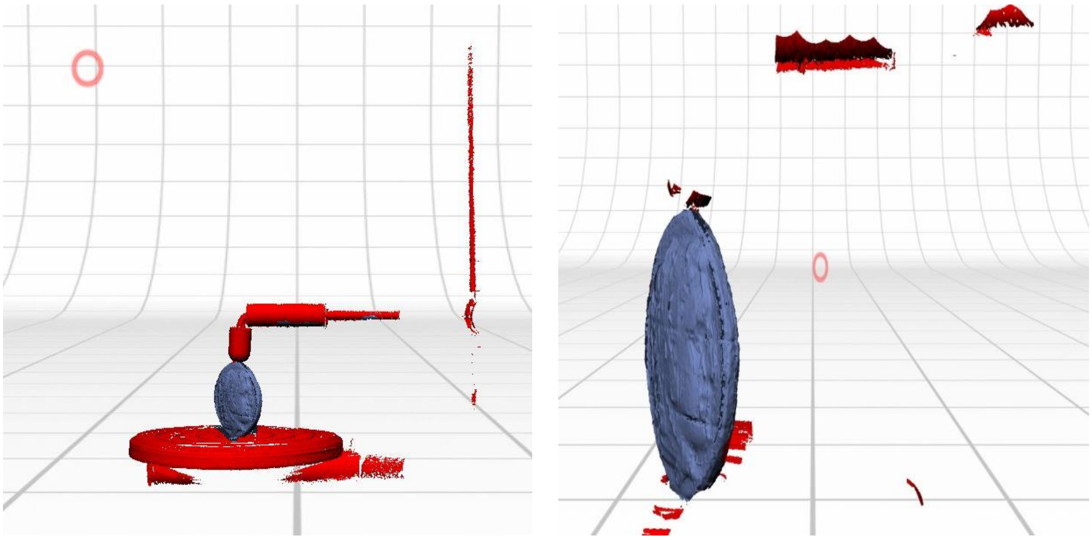


Fig 12.2 Selection of unwanted portions of scanned data for trimming
Ref. Screenshot taken by software

The trimming process will be repeated for the final noise elimination as depicted at Fig.12.3.

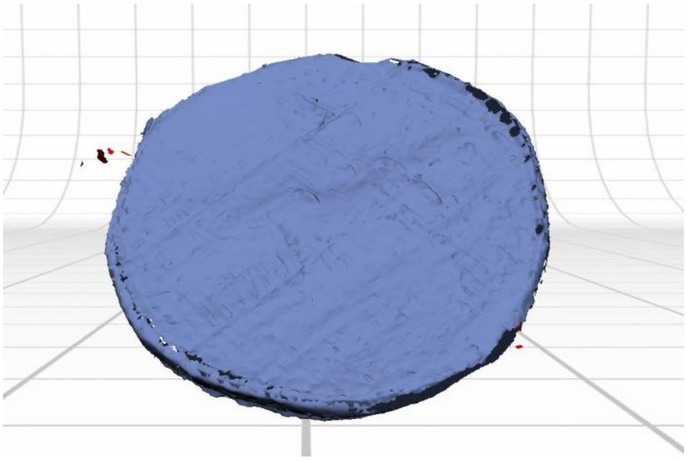


Fig 12.3 Elimination of remaining noise at the coin
Ref. Screenshot taken by software

With the noise eliminated the scans can be subjected to alignment so that a single family of scan to derive.

Alignment

This phase enables the user to align the multiple scans came from scanning stage by use of incorporated tools provided by the software for this purpose. Align option requires the emplacement of pins attached to very obvious points of the scanned object and results to a conjunction of those multiple scans in one scan. By pushing the align icon the Align command will be activated (Fig.12.4).

Fig 12.4 Align command enablement
Ref. Screenshot taken by software

The model can be renamed by the yellow bar as shown at Fig.12.5

Fig 12.5 Model rename bar
Ref. Screenshot taken by software

With the Align command activated the screen is split in two, and two identical spaces with the first scan families of the coin will appear as shown in Fig.12.6

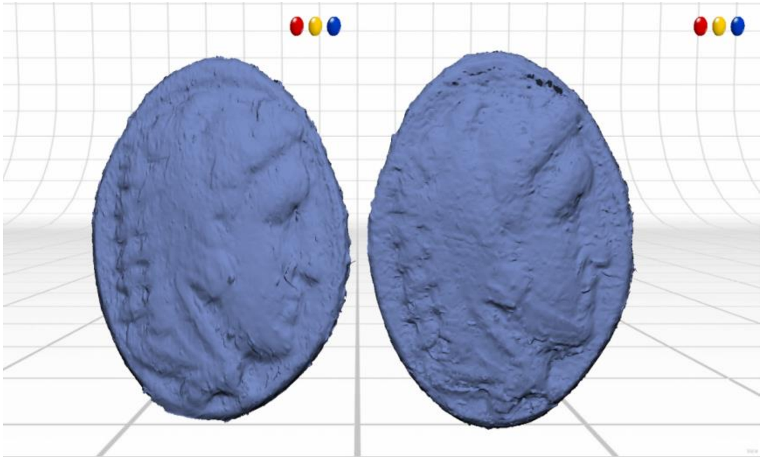
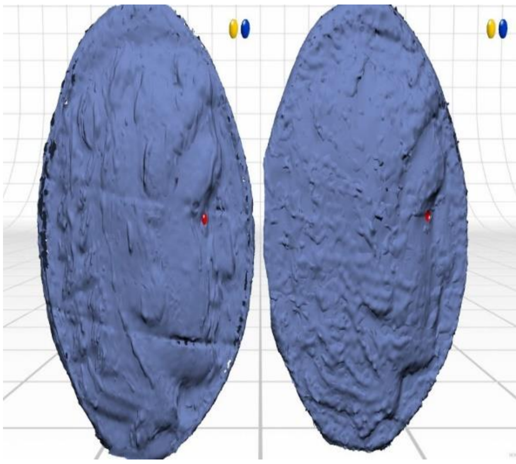
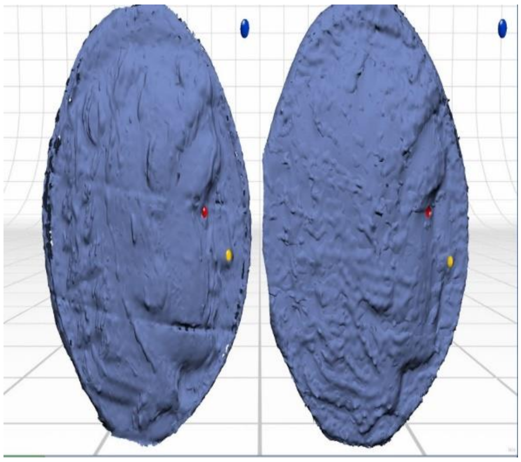


Fig 12.6 The initial interface of Align command
Ref. Screenshot taken by software

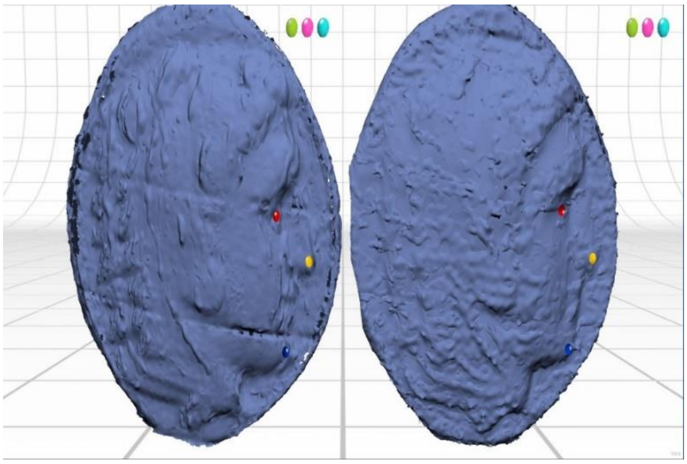
For proceeding with the alignment some pins should be placed at obvious points of the object which are the common entities in every scan family and will be used for stitching the multiple scans together. The minimum amount of pins to be placed so that the align command to be performed is minimum three as shown at Fig.12.7



Emplacement of one pin



Emplacement of two pins



Emplacement of three pins

With the emplacement of the third pin the information tab notify us that the align command can be performed

Fig 12.7 Align command procedure
Ref. Screenshot taken by software

Fuse

With the scanned faces trimmed and aligned the next step is the fusion of those multiple scan families in one. By the Fuse button on the main toolbar the Fuse command is activated (Fig 12.8) and the fuse toolbar pops up (Fig 12.9) enabling the settings.

Fig 12.8 Fuse command
Ref. Screenshot taken by software

Fig 12.9 Fuse interface
Ref. Screenshot taken by software

For the coin fuse process the deviation tolerance will be left at 0.0025".Fusion has the ability of simplification, which keeps more points in intricate areas and fewer points in larger planes. Besides the tolerance configuration Fusion settings gives the ability of automatic manipulation of the align errors ,such as holes, or water tight models, or customizing the resolution ratio and enables blending texture as shown at Fig 12.10.

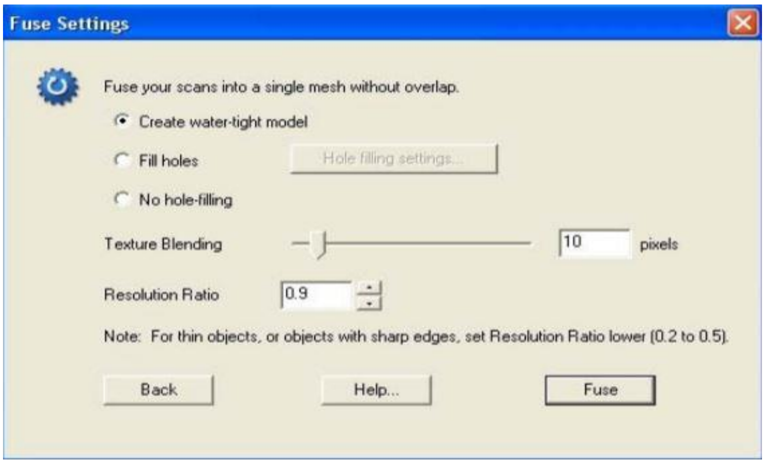


Fig 12.10 Fuse advance settings
Ref. Screenshot taken by software

For the coin the resolution ration was set to 1.0. When the desired configurations regarding fusion are set the process is then performed. as shown at Fig.12.11

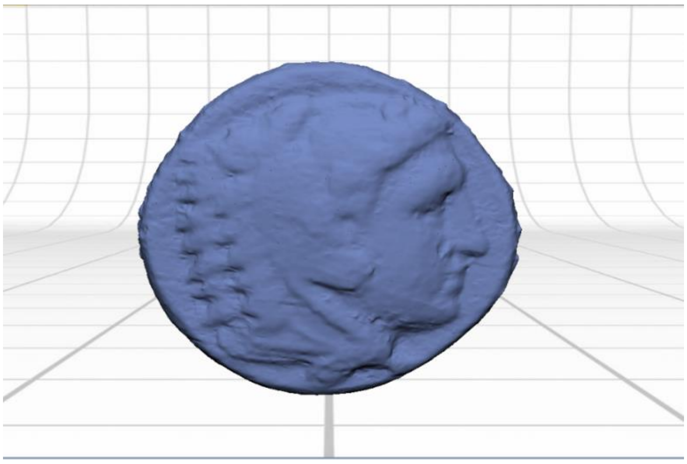


Fig 12.11 The coin after Fuse command
Ref. Screenshot taken by software

12.1.1. Export as *stl format

By activating the “output” command in the main toolbar the stl format is selected so that the data to be converted as shown at Fig 12.12

Fig 12.12 Export to *stl format
Ref. Screenshot taken by software

12.2. SLA coin procedure

The scanned data of the coin are imported in Scanstudio as shown at Fig.12.13

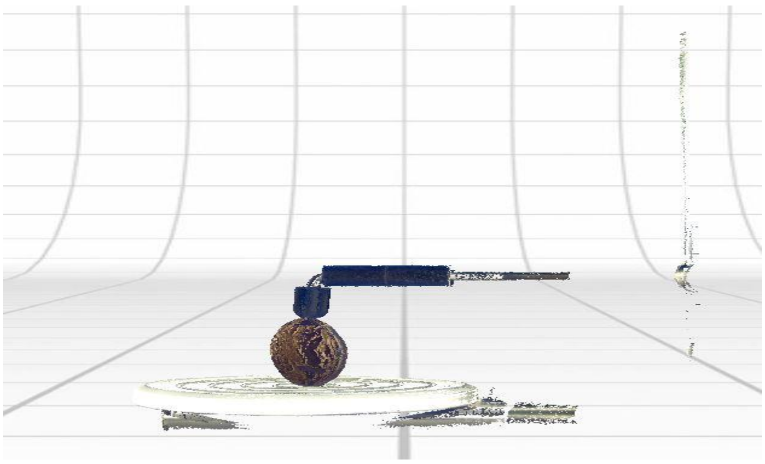


Fig 12.13 Import the coin in Scanstudio
Ref. Screenshot taken by software

The unwanted portions are marked and appeared in red color as shown at Fig.12.14

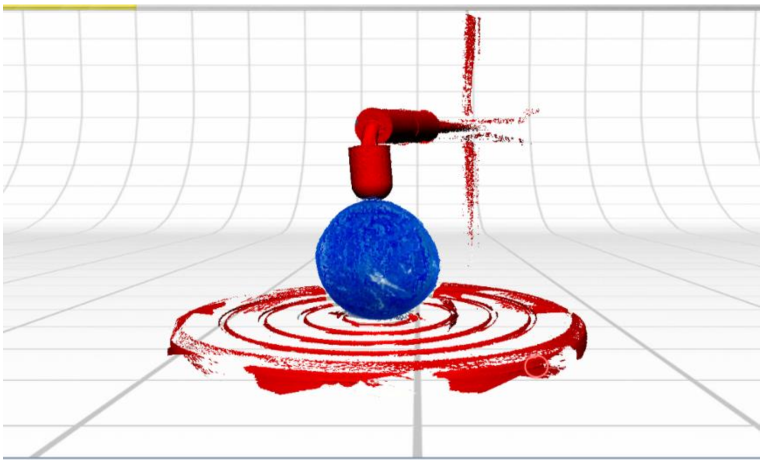


Fig 12.14 Selection of unwanted portions of scanned data for trimming
Ref. Screenshot taken by software

With use of Trim option the marked portions are trimmed. The trim process is repeated until all the noise is eliminated.

Alignment

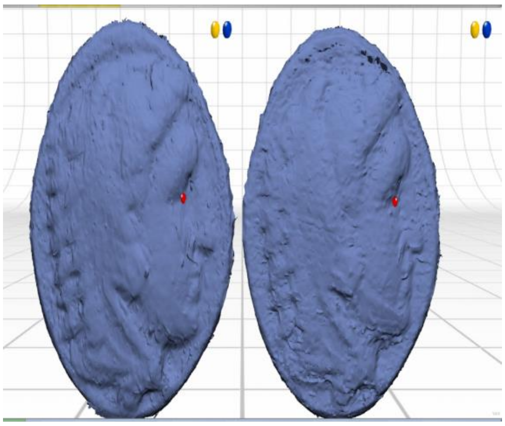
By pushing the align icon the Align command will be activated (Fig.12.15).

Fig 12.15 Align command enablement
Ref. Screenshot taken by software

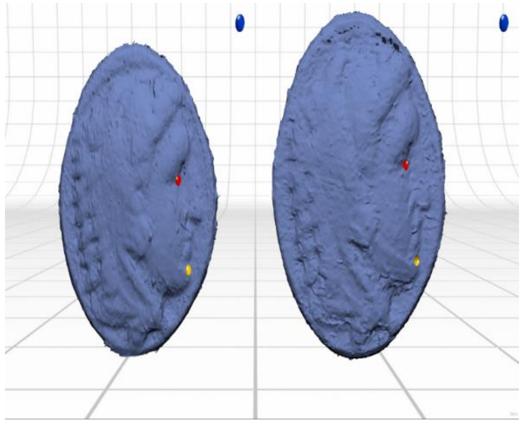
The model can be renamed by the yellow bar as shown at Fig.12.16

Fig 12.16 Model rename bar
Ref. Screenshot taken by software

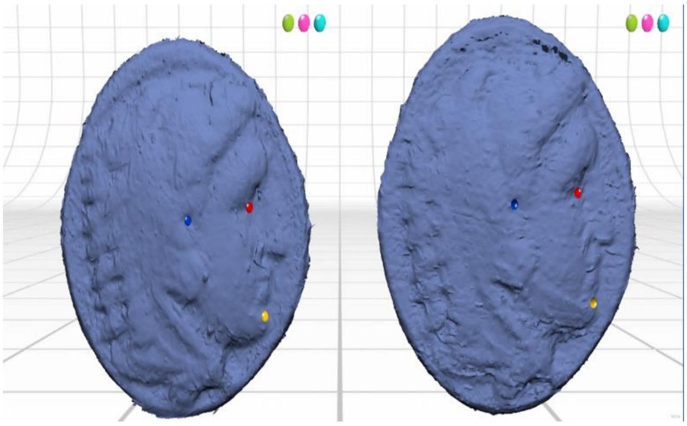
In order to proceed with the alignment at least three pins should be placed as shown at Fig.12.17



Emplacement of one pin



Emplacement of two pins



Emplacement of three pins

Fig 12.17 Align command procedure
Ref. Screenshot taken by software

The align command is activated and the result is depicted at Fig.12.18

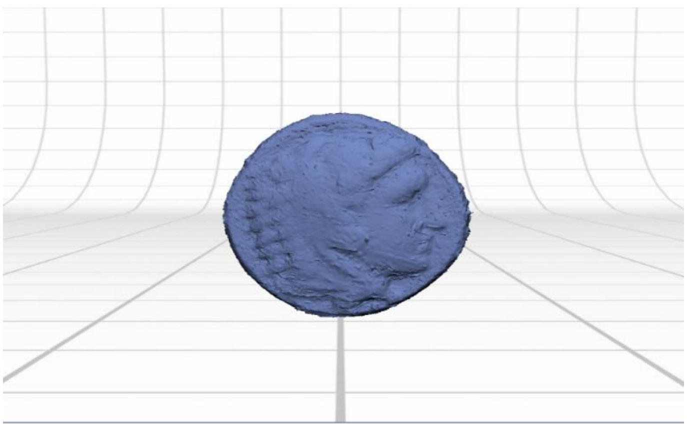


Fig 12.18 Align completed
Ref. Screenshot taken by software

Fuse

By the Fuse button on the main toolbar the Fuse command is activated (Fig 12.19) and the fuse toolbar pops up (Fig 12.20) enabling the settings.

Fig 12.19 Fuse command activation
Ref. Screenshot taken by software

Fig 12.20 Fuse interface
Ref. Screenshot taken by software

For the coin fuse process the deviation tolerance will be left at 0.0025".Fusion has the ability of simplification, which keeps more points in intricate areas and fewer points in larger planes. Besides the tolerance configuration Fusion settings gives the ability of automatic manipulation of the align errors ,such as holes, or water tight models, or customizing the resolution ratio and enables blending texture as shown at Fig 12.21.

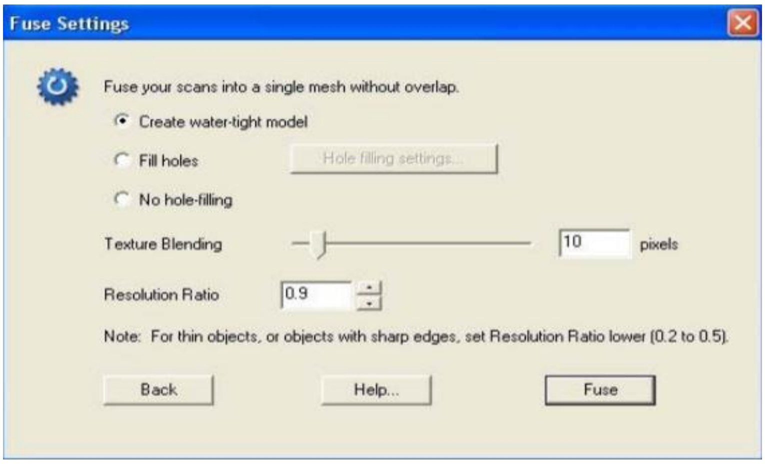


Fig 12.21 Fuse advance settings
Ref. Screenshot taken by software

For the coin the resolution ration was set to 1.0.When the desired configurations regarding fusion are set the process is then performed. as shown at Fig.12.22

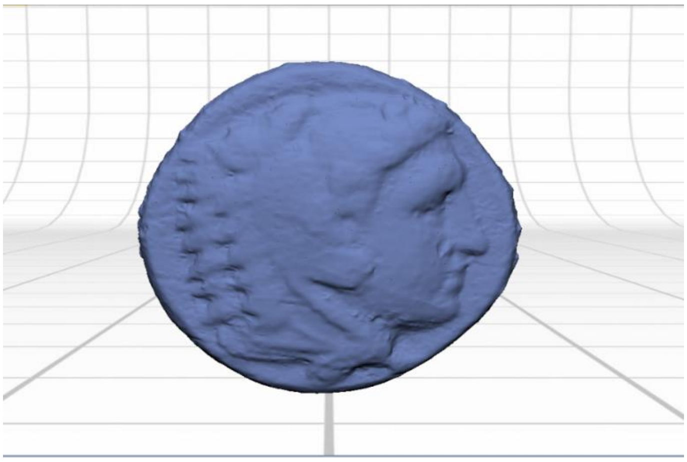


Fig 12.22 SLA coin after Fuse
Ref. Screenshot taken by software

12.3.1. Export as *stl format

By activating the “output” command in the main toolbar the stl format is selected so that the data to be converted as shown at Fig. 12.23

Fig 12.23 export to *stl format
Ref. Screenshot taken by software

12.3. Plaster Coin

The scanned data of the coin are imported in Scanstudio as shown at Fig.12.24

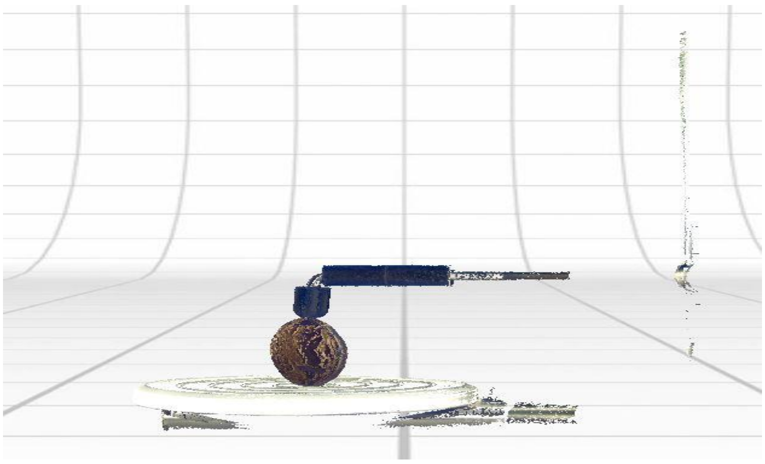


Fig 12.24 Import the coin in Scanstudio
Ref. Screenshot taken by software

The unwanted portions are marked and appeared in red color as shown at Fig.12.25

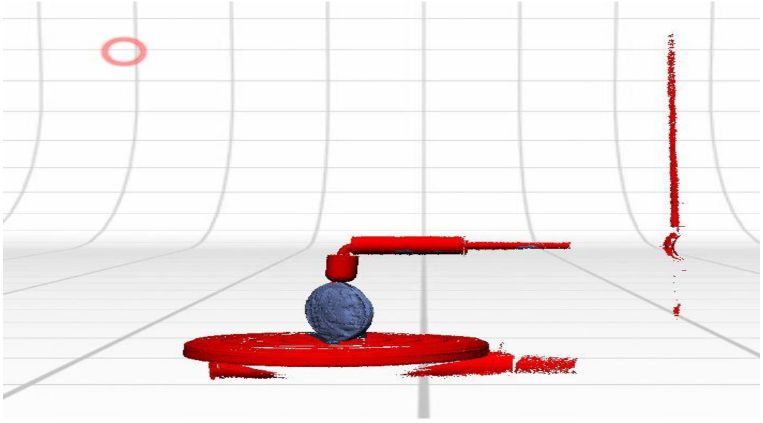


Fig 12.25 Selection of unwanted portions of scanned data for trimming
Ref. Screenshot taken by software

With use of Trim option the marked portions are trimmed. The trim process is repeated until all the noise is eliminated.

Alignment

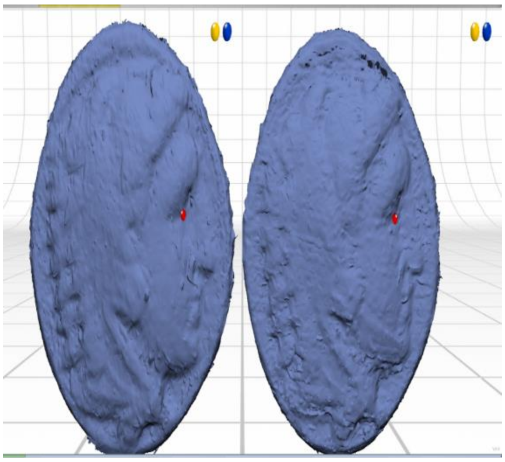
By pushing the align icon the Align command will be activated (Fig.12.26).

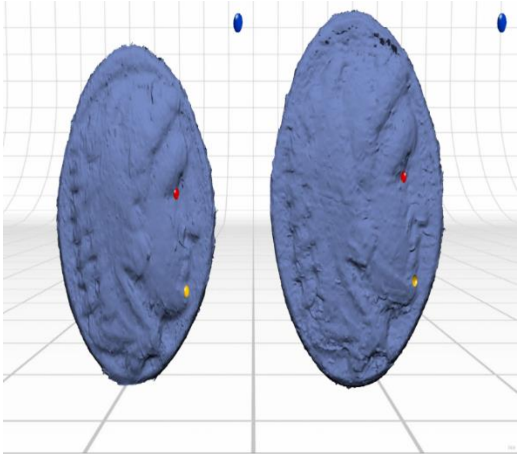
Fig 12.26 Align command enablement
Ref. Screenshot taken by software

The model can be renamed by the yellow bar as shown at Fig.12.27

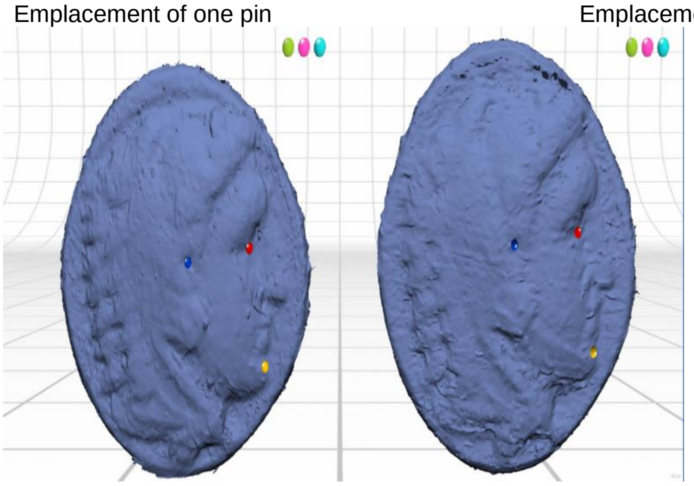
Fig 12.27 Model rename bar
Ref. Screenshot taken by software

In order to proceed with the alignment at least three pins should be placed as shown at Fig.12.28





Emplacement of one pin Emplacement of two pins



Emplacement of three pins

Fig 12.28 Align command procedure
Ref. Screenshot taken by software

The align command is activated and the result is depicted at Fig. 12.29

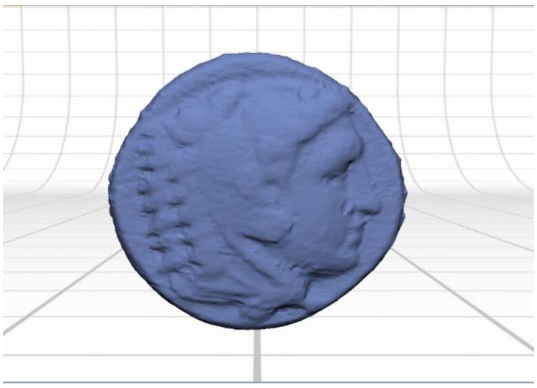


Fig 12.29. Align command completed
Ref. Screenshot taken by software

Fuse

By the Fuse button on the main toolbar the Fuse command is activated (Fig 12.30) and the fuse toolbar pops up (Fig 12.31) enabling the settings.

Fig 12.30 Fuse command activation
Ref. Screenshot taken by software

Fig 12.31 Fuse interface
Ref. Screenshot taken by software

For the coin fuse process the deviation tolerance will be left at 0.0025".Fusion has the ability of simplification, which keeps more points in intricate areas and fewer points in larger planes. Besides the tolerance configuration Fusion settings gives the ability of automatic manipulation of the align errors ,such as holes, or water tight models, or customizing the resolution ratio and enables blending texture as shown at Fig 12.32.

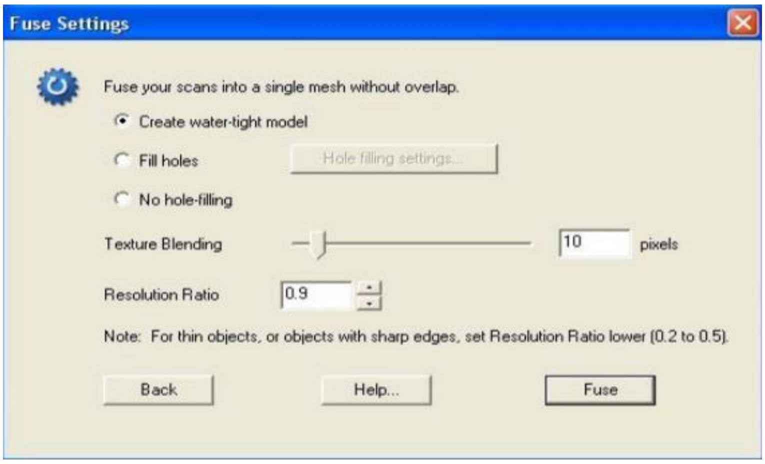


Fig 12.32 Fuse advance settings
Ref. Screenshot taken by software

For the coin the resolution ration was set to 1.0.When the desired configurations regarding fusion are set the process is then performed. as shown at Fig.12.33.

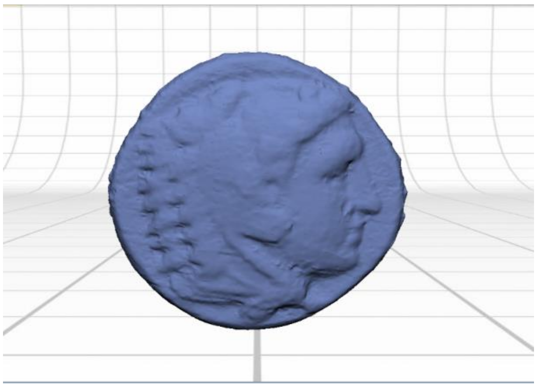


Fig 12.33 SLA coin after Fuse
Ref. Screenshot taken by software

12.3.1. Export as *stl format

By activating the "output" command in the main toolbar the stl format is selected so that the data to be converted as shown at Fig. 12.34

Fig 12.34 Export to *stl format
Ref. Screenshot taken by software

12.4. FDM positive die

The scanned data of the coin are imported in Scanstudio as shown at Fig.12.35

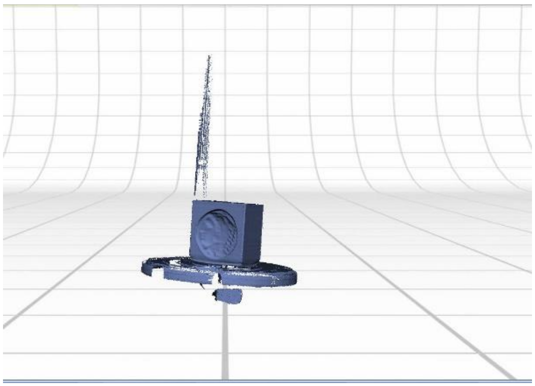


Fig 12.35 The imported Positive die
Ref. Screenshot taken by software

The unwanted portions are marked and appeared in red color as shown at Fig.12.36.

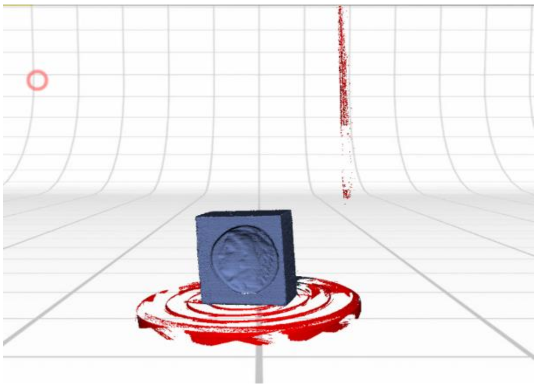


Fig 12.36 Selection of unwanted portions of scanned data for trimming
Ref. Screenshot taken by software

With use of Trim option the marked portions are trimmed. The trim process is repeated until all the noise is eliminated.

Alignment

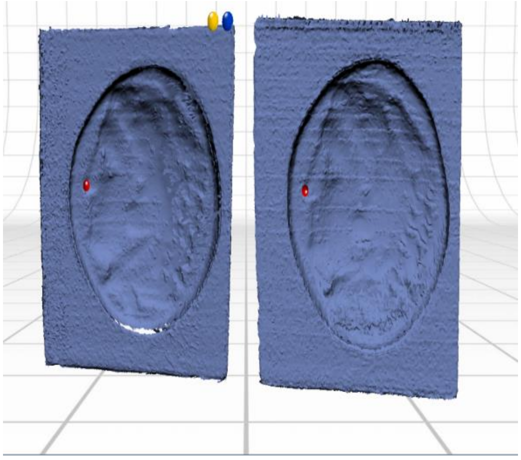
By pushing the align icon the Align command will be activated (Fig.12.37).

Fig 12.37 Align command enablement
Ref. Screenshot taken by software

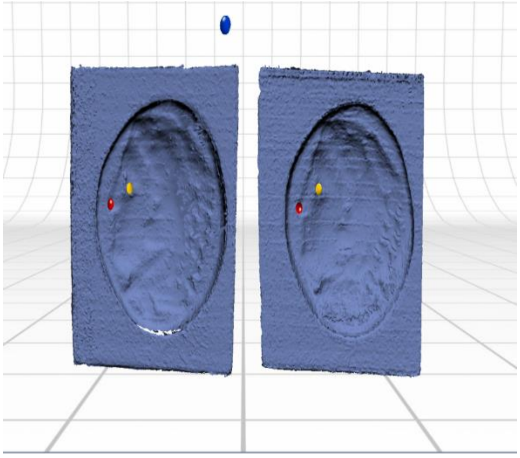
The model can be renamed by the yellow bar as shown at Fig 12.38

Fig 12.38 Model rename bar
Ref. Screenshot taken by software

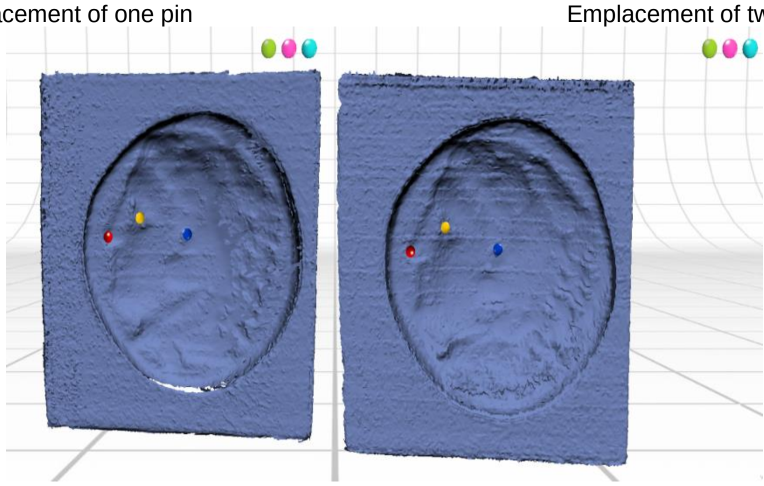
In order to proceed with the alignment at least three pins should be placed as shown at Fig.12.39.



Emplacement of one pin



Emplacement of two pins



Emplacement of three pins

Fig.12.39 Align command procedure
Ref. Screenshot taken by software

The align command is performed and the result is depicted at Fig.12.40

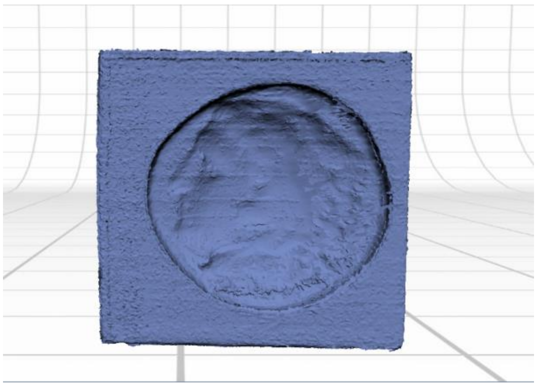


Fig 12.40 Align command completed
Ref. Screenshot taken by software

Fuse

By the Fuse button on the main toolbar the Fuse command is activated (Fig 12.41) and the fuse toolbar pops up (Fig 12.42) enabling the settings.

Fig 12.41 Fuse command activation
Ref. Screenshot taken by software

Fig 12.42 Fuse interface
Ref. Screenshot taken by software

The toolbar consists of a slider which is appointed for the specification of the wanted deviation tolerance for the decimation. 0.00" simplification won't have any effect on the data but as the simplification slider increases the value of tolerance the model will be simplified and the file size will get smaller. For the coin fuse process the deviation tolerance will be left at 0.0025".Fusion has the ability of simplification, which keeps more points in intricate areas and fewer points in larger planes. Besides the tolerance configuration Fusion settings gives the ability of automatic manipulation of the align errors ,such as holes, or water tight models, or customizing the resolution ratio and enables blending texture as shown at Fig 12.43.

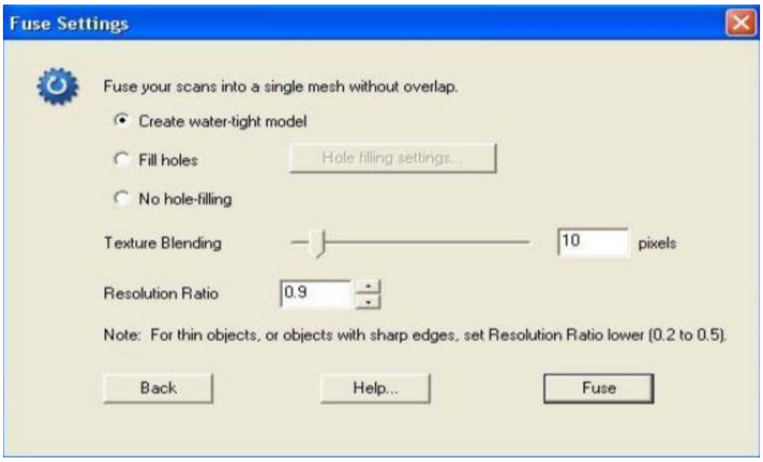


Fig 12.43 Fuse advance settings
Ref. Screenshot taken by software

For the die the resolution ration was set to 1.0. Values less than 1 will decrease your triangle size. Values greater than 1 will increase your triangle. When the desired configurations regarding fusion are set the process is then performed. as shown at Fig.12.44.

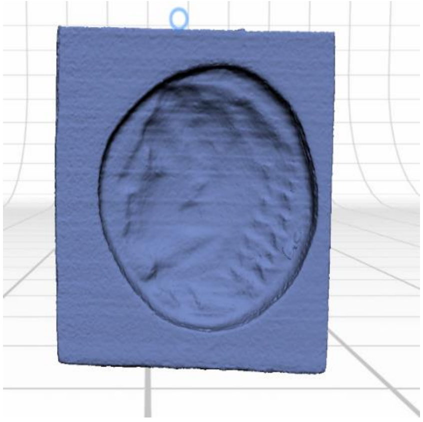


Fig 12.44 FDM positive Die after Fuse
Ref. Screenshot taken by software

12.4.1. Export as *stl format

By activating the “output” command in the main toolbar the stl format is selected so that the data to be converted as shown at Fig. 12.45

Fig 12.45 Export to *stl format
Ref. Screenshot taken by software

12.5. FDM Negative Die

The scanned data of the coin are imported in Scanstudio as shown at Fig.12.46

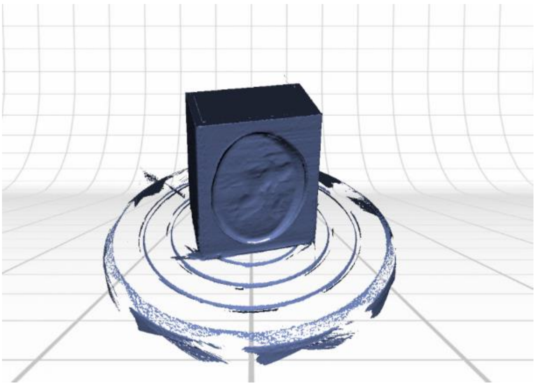


Fig 12.46 The imported Negative die
Ref. Screenshot taken by software

The unwanted portions are marked and appeared in red color as shown at Fig.12.47

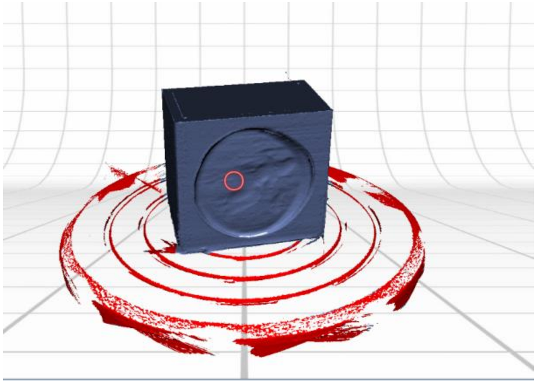


Fig 12.47 Selection of unwanted portions of scanned data for trimming
Ref. Screenshot taken by software

With use of Trim option the marked portions are trimmed. The trim process is repeated until all the noise is eliminated.

Alignment

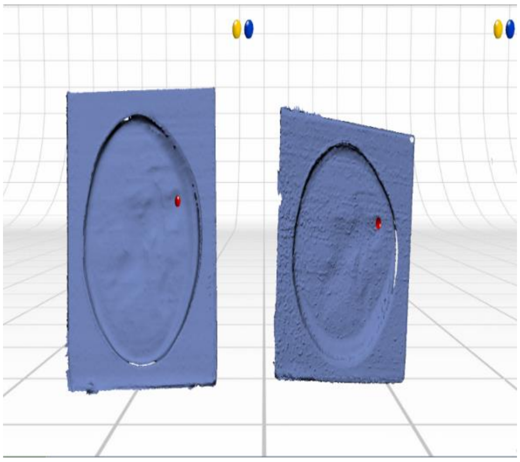
By pushing the align icon the Align command will be activated (Fig.12.48)

Fig 12.48 Align command enablement
Ref. Screenshot taken by software

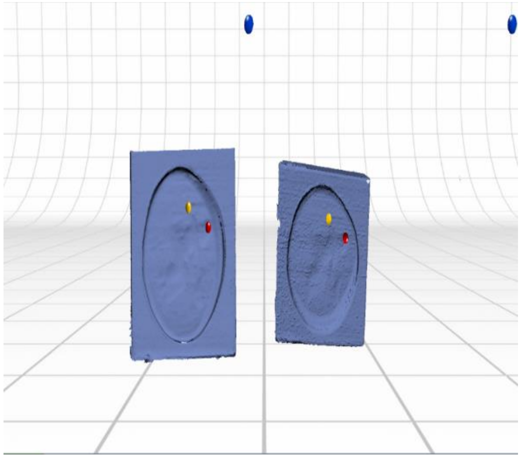
The model can be renamed by the yellow bar as shown at Fig.12.49

Fig 12.49 Model rename bar
Ref. Screenshot taken by software

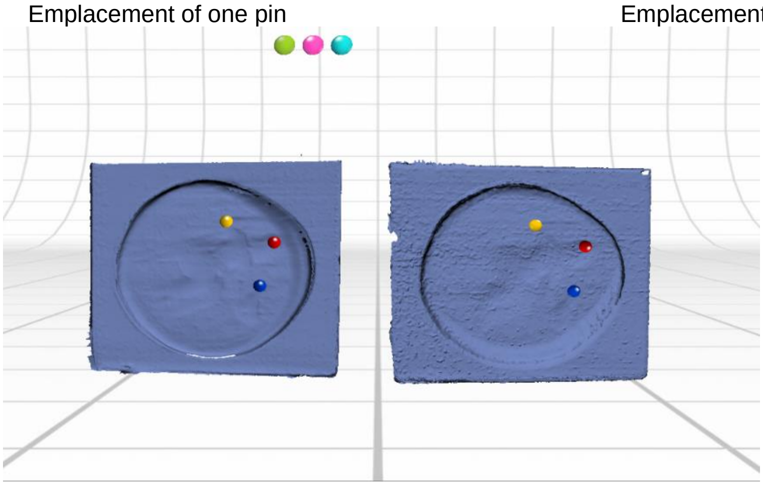
In order to proceed with the alignment at least three pins should be placed as shown at Fig. 12.50



Emplacement of one pin



Emplacement of two pins



Emplacement of three pins

Fig 12.50 Align command procedure
Ref. Screenshot taken by software

The align command is activated and the result is depicted at Fig.12.51

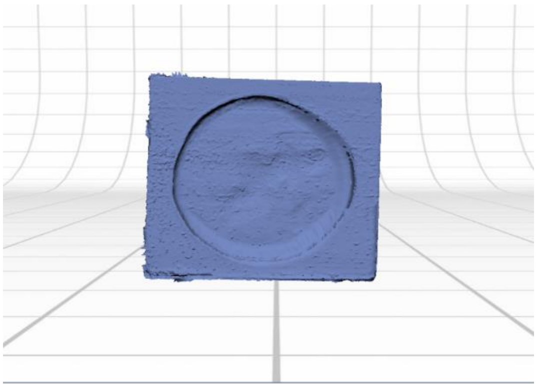


Fig 12.51 Align command completed
Ref. Screenshot taken by software

Fuse

By the Fuse button on the main toolbar the Fuse command is activated (Fig 12.52) and the fuse toolbar pops up (Fig 12.53) enabling the settings.

Fig 12.52 Fuse command activation
Ref. Screenshot taken by software

Fig 12.53 Fuse interface
Ref. Screenshot taken by software

For the coin fuse process the deviation tolerance will be left at 0.0025”.Fusion has the ability of simplification, which keeps more points in intricate areas and fewer points in larger planes. Besides the tolerance configuration Fusion settings gives the ability of automatic manipulation of the align errors ,such as holes, or water tight models, or customizing the resolution ratio and enables blending texture as shown at Fig.12.54

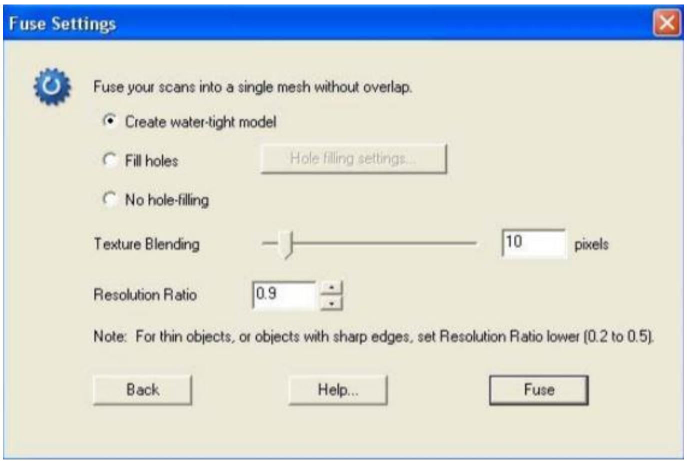


Fig 12.54 Fuse advance settings
Ref. Screenshot taken by software

For the die the resolution ration was set to 1.0. When the desired configurations regarding fusion are set the process is then performed as shown at Fig.12.55

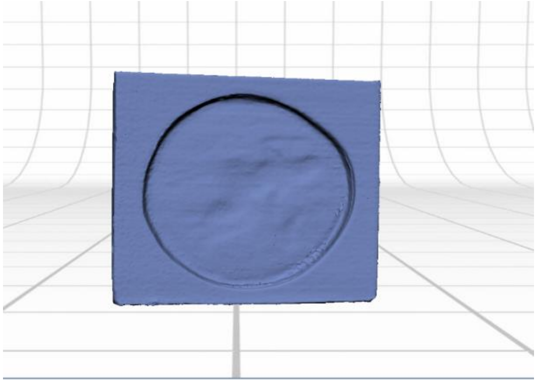


Fig 12.55 FDM positive Die after Fuse
Ref. Screenshot taken by software

12.5.1. Export as *stl format

By activating the “output” command in the main toolbar the stl format is selected so that the data to be converted as shown at Fig. 12.56

Fig 12.56 Export to *stl format
Ref. Screenshot taken by software

12.6. SLA Positive Die

The scanned data of the coin are imported in Scanstudio as shown at Fig.12.57

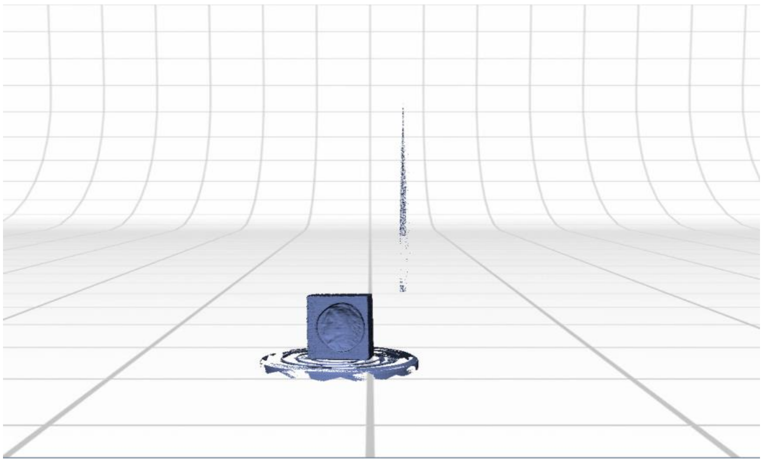


Fig 12.57 The imported Positive Die
Ref. Screenshot taken by software

The unwanted portions are marked and appeared in red color as shown at Fig.12.58

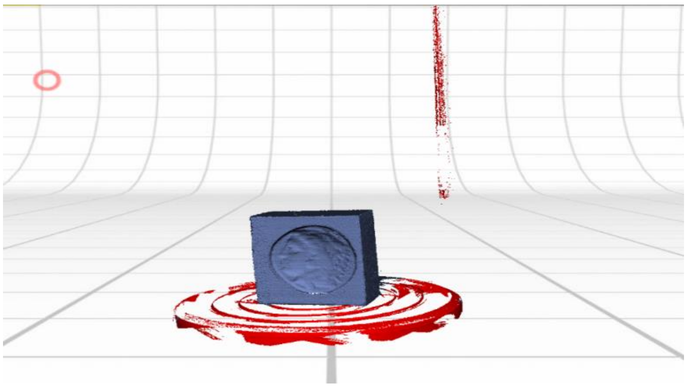


Fig 12.58 Selection of unwanted portions of scanned data for trimming
Ref. Screenshot taken by software

With use of Trim option the marked portions are trimmed. The trim process is repeated until all the noise is eliminated.

Alignment

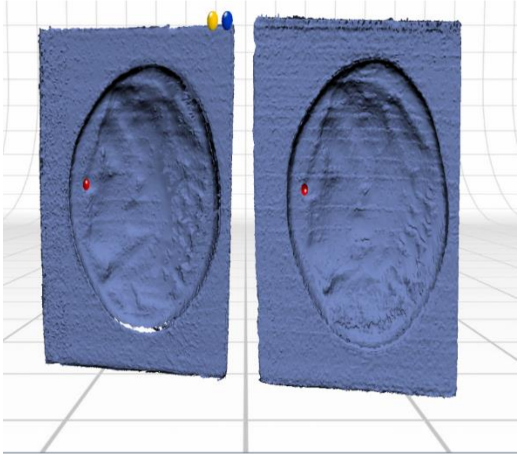
By pushing the align icon the Align command will be activated (Fig.12.59)

Fig 12.59 Align command enablement
Ref. Screenshot taken by software

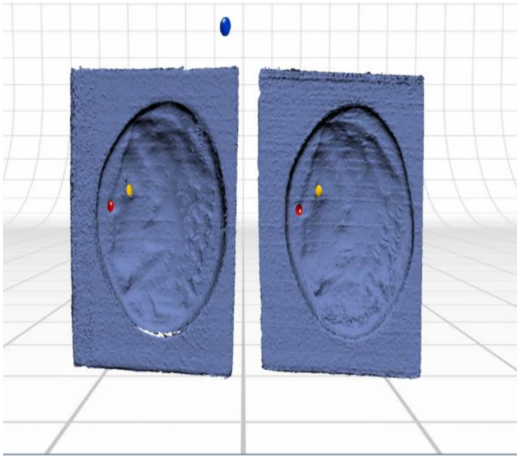
The model can be renamed by the yellow bar as shown at Fig.12.60

Fig 12.60 Model rename bar
Ref. Screenshot taken by software

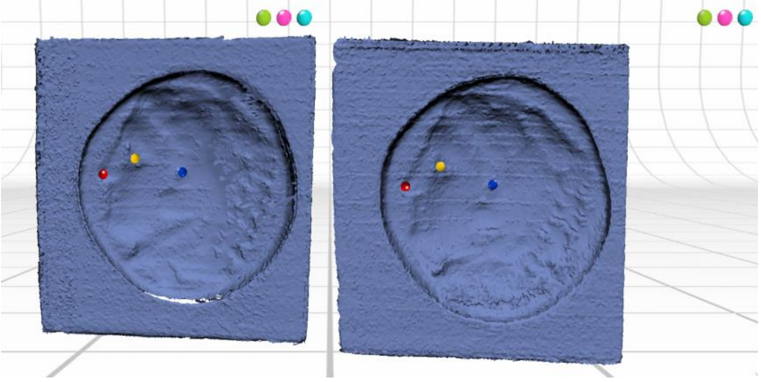
In order to proceed with the alignment at least three pins should be placed as shown at Fig.12.61



Emplacement of one pin



Emplacement of two pins



Emplacement of three pins

Fig. 12.61 Align command procedure
Ref. Screenshot taken by software

The align command is activated and the result is depicted at Fig.12.62

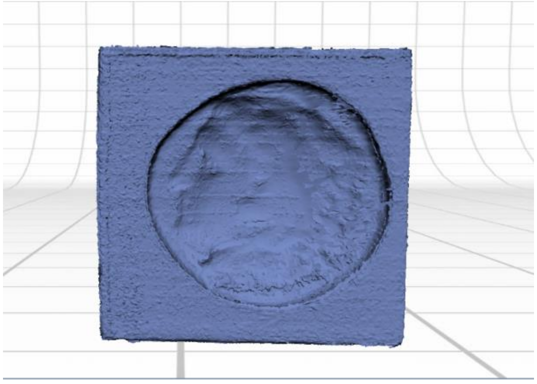


Fig 12.62 Align command completed
Ref. Screenshot taken by software

Fuse

By the Fuse button on the main toolbar the Fuse command is activated (Fig. 12.63) and the fuse toolbar pops up (Fig.12.64) enabling the settings.

Fig 12.63 Fuse command activation
Ref. Screenshot taken by software

Fig 12.64 Fuse interface
Ref. Screenshot taken by software

For the coin fuse process the deviation tolerance will be left at 0.0025".Fusion has the ability of simplification, which keeps more points in intricate areas and fewer points in larger planes. Besides the tolerance configuration Fusion settings gives the ability of automatic manipulation of the align errors ,such as holes, or water tight models, or customizing the resolution ratio and enables blending texture as shown at Fig 12.65

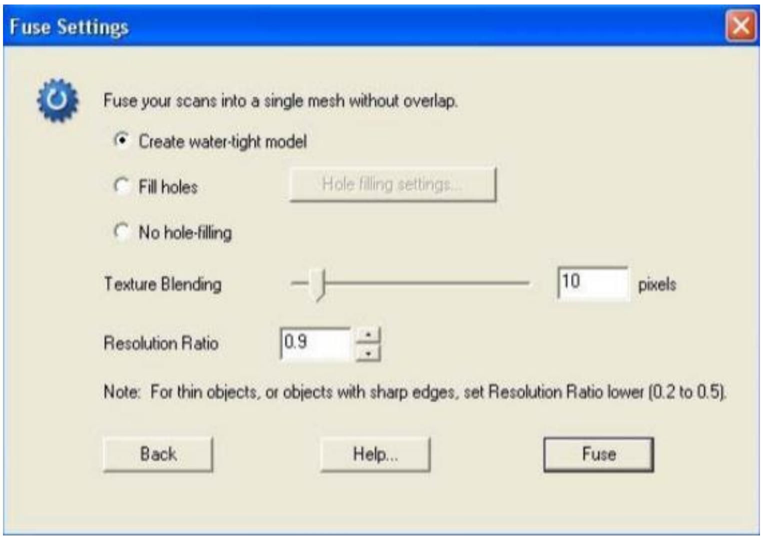


Fig 12.65 Fuse advance settings
Ref. Screenshot taken by software

For the die the resolution ration was set to 1.0. When the desired configurations regarding fusion are set the process is then performed. as shown at Fig.12.66

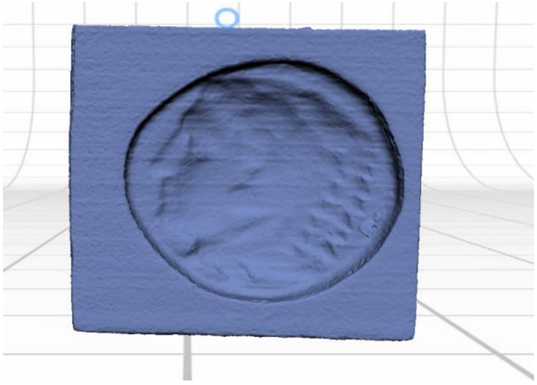


Fig 12.66 SLA Positive Die after Fuse
Ref. Screenshot taken by software

12.6.1. Export as *stl format

By activating the “output” command in the main toolbar the stl format is selected so that the data to be converted as shown at Fig. 12.67

Fig 12.67 Export to *stl format
Ref. Screenshot taken by software

12.7. SLA Negative Die

The scanned data of the coin are imported in Scanstudio as shown at Fig.12.68

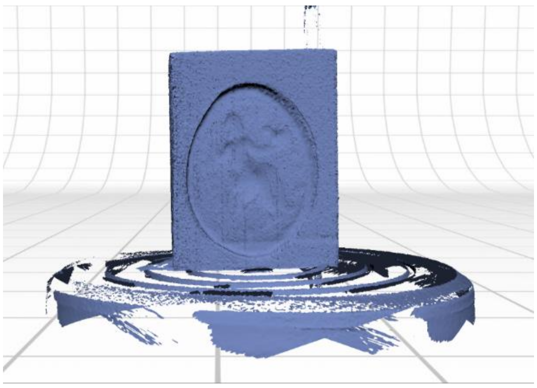


Fig 12.68 The imported Negative Die
Ref. Screenshot taken by software

The unwanted portions are marked and appeared in red color as shown at Fig.12.69

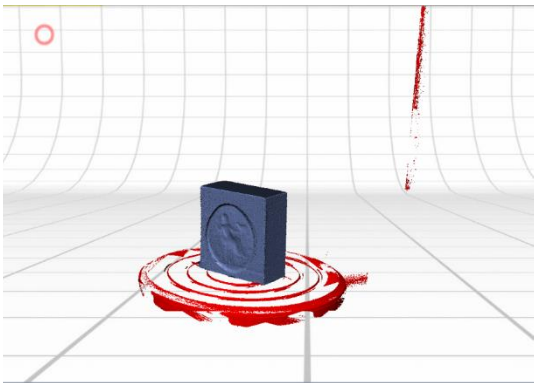


Fig 12.69 Selection of unwanted portions of scanned data for trimming
Ref. Screenshot taken by software

With use of Trim option the marked portions are trimmed. The trim process is repeated until all the noise is eliminated.

Alignment

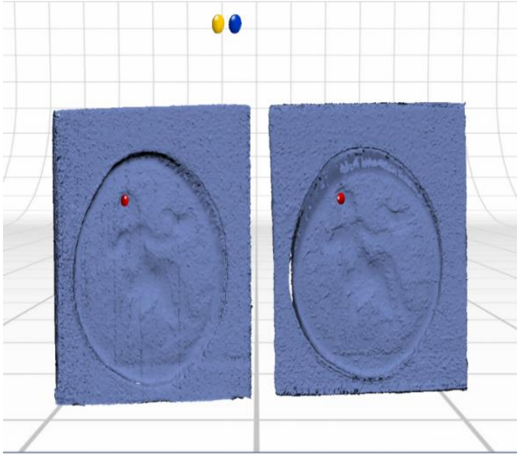
By pushing the align icon the Align command will be activated (Fig.12.70).

Fig 12.70 Align command enablement
Ref. Screenshot taken by software

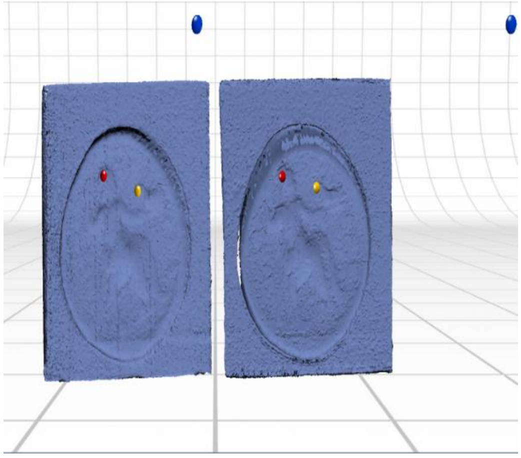
The model can be renamed by the yellow bar as shown at Fig.12.71

Fig 12.71 Model rename bar
Ref. Screenshot taken by software

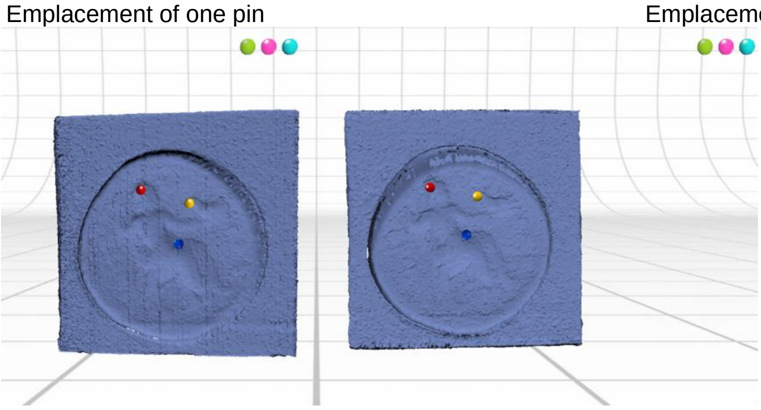
In order to proceed with the alignment at least three pins should be placed as shown at Fig.12.72



Emplacement of one pin



Emplacement of two pins



Emplacement of three pins

Fig 12.72 Align command procedure
Ref. Screenshot taken by software

The align command is activated and the result is depicted at Fig 12.73

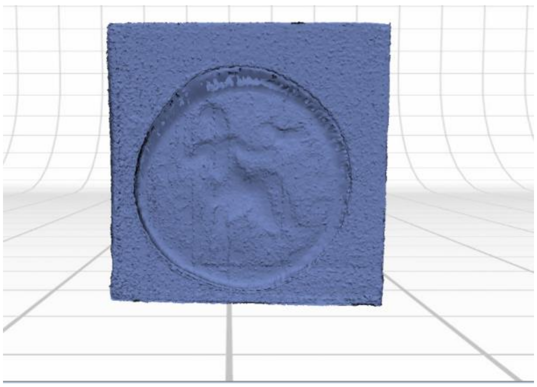


Fig 12.73 Align command completed
Ref. Screenshot taken by software

Fuse

By the Fuse button on the main toolbar the Fuse command is activated (Fig 12.74) and the fuse toolbar pops up (Fig 12.75) enabling the settings.

Fig 12.74 Fuse command activation
Ref. Screenshot taken by software

Fig 12.75 Fuse interface
Ref. Screenshot taken by software

For the coin fuse process the deviation tolerance will be left at 0.0025”.Fusion has the ability of simplification, which keeps more points in intricate areas and fewer points in larger planes. Besides the tolerance configuration Fusion settings gives the ability of automatic manipulation of the align errors ,such as holes, or water tight models, or customizing the resolution ratio and enables blending texture as shown at Fig 12.76

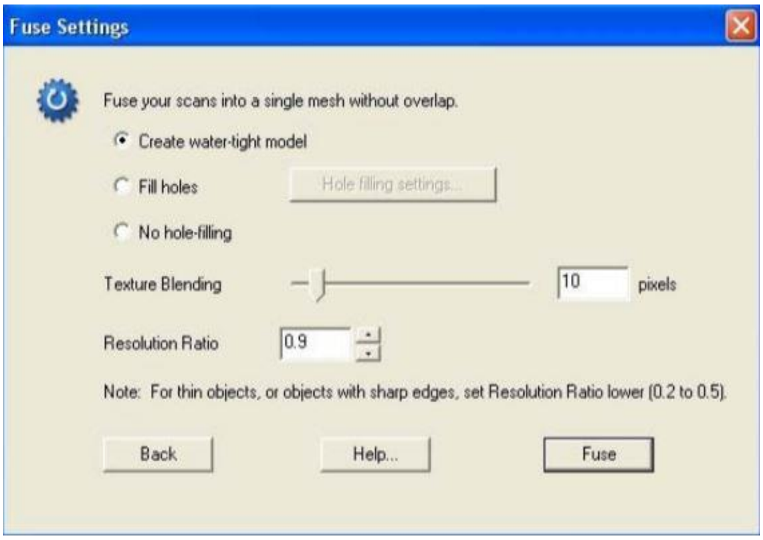


Fig 12.76 Fuse advance settings
Ref. Screenshot taken by software

For the die the resolution ration was set to 1.0. When the desired configurations regarding fusion are set the process is then performed. as shown at Fig.12.77

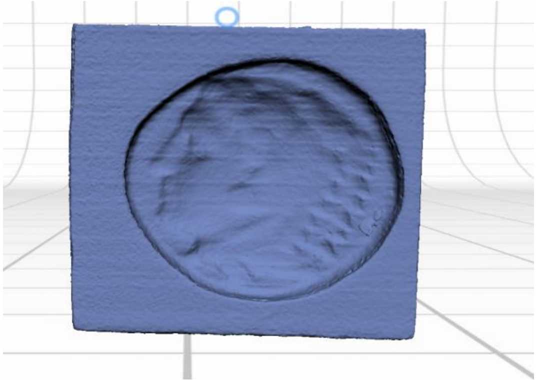


Fig 12.77 SLA Negative Die after Fuse
Ref. Screenshot taken by software

12.7.1. Export as *stl format

By activating the “output” command in the main toolbar the stl format is selected so that the data to be converted as shown at Fig. 12.78

Fig 12.78 export to *stl format
Ref. Screenshot taken by software

13. MANIPULATION OF THE STL FILES USING MESHMIXER

In this chapter the manipulation of the obtained STL files will be presented. The manipulation will take place for reducing the file size of the coins and dies through reconstruction of the mesh in order to be imported afterwards in Artec Studio for the deviation analysis

13.1. FDM coin manipulation process

The stl file containing the FDM coin data is initially very big in size something that is prohibited in order to be subjected to deviation analysis. The coin should be rotated and placed with the imprint facing the front view using the Transform option as shown at Fig.13.1.

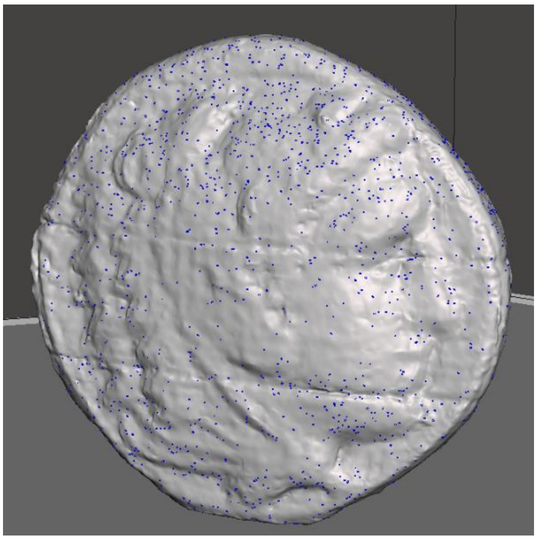
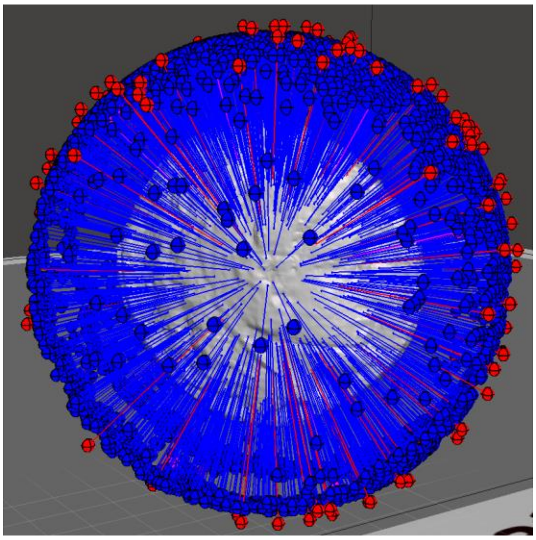


Fig 13.1 Emplacement of the coin on Meshmixer platform
Ref. Screenshots taken by Meshmixer

For making the file compatible so that it can be imported for deviation analysis in Artec Studio the file will be first inspected for any possible flaws using the “Inspector” option With the command execution the model appear to have several holes as shown at Fig.13.2., which can be filled either manually or automatically using the “Auto Repair” option as depicted at Fig.13.3.



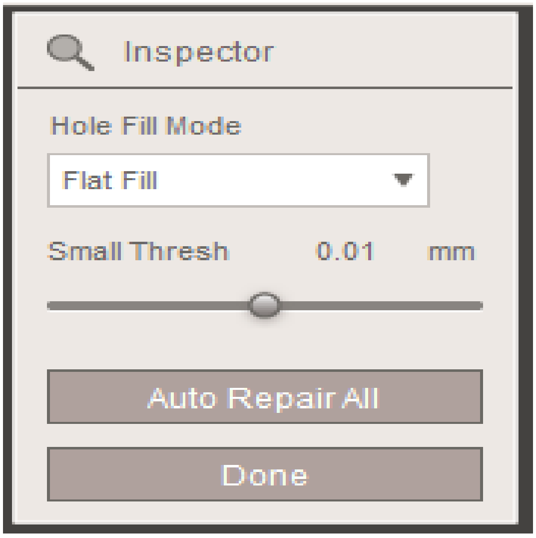


Fig 13.2 Inspector Command depicting that the model is not watertight

Fig 13.3 Automatic Repair of the holes

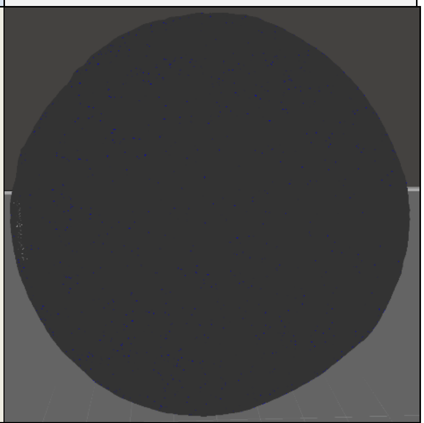
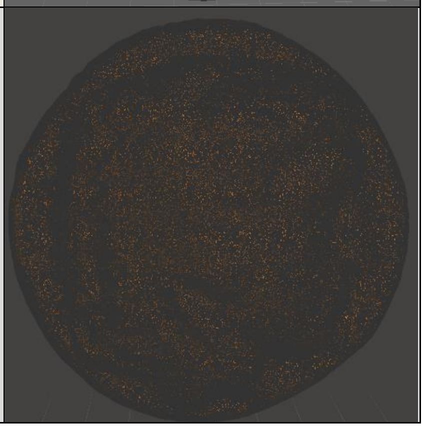
Ref. Screenshots taken by Meshmixer

After the model is watertight it should be converted to solid part in order to be further processed. This will happen with the “Convert to Solid” command as depicted at Fig.13.4.

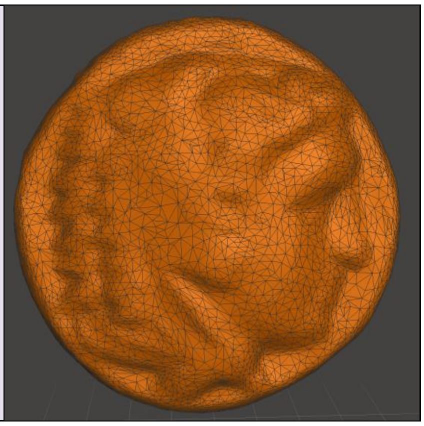
Fig 13.4 Convert to solid option
Ref. Screenshots taken by Meshmixer

Now that the coin is converted to solid part the manipulation procedure will begin using the Reduce command several times until the file size is reduced as much as the details of the imprint not to be deteriorated as depicted at Table 13.1.

Table 13.1 Coin grid and file size after Reduce process

	Vertices/ Triangles	**Wireframe**
Default Values	1791124/ 3582244	
Reduce No 1	889343/ 1778682	

Reduce No 2	448169/ 886341	
Reduce No 3	222394/ 444670	
Reduce No 4	111691/ 222334	
Reduce No 5	55585/ 111166	

Fail Reduce No 6	306271/ 61250	

The mesh regeneration took place through sequential reduction of the number of triangles by 50% each time and repeated itself until the illustration of the iconography started to deteriorate as shown at the wireframe of Reduce No 6. A noticeable fact for the whole procedure is the difference in illumination affect deriving from the very coarse initial mesh of the coin and this explain the fact that the file size was so big. By iterating the reduction sequence the mesh becomes sparse, thus more visible until the last iteration at which the mesh is smooth enough so that all the iconography details to be fully visible. This information can derive besides observing the number of triangles or the depiction of the wireframe by the file size as well which has been dramatically reduced. The same principle will be used for the remaining six objects.

13.2. FDM positive die manipulation process

The positive die is imported on Meshmixer as shown at Fig.13.5

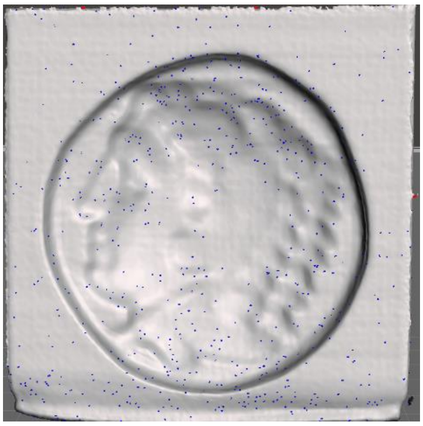
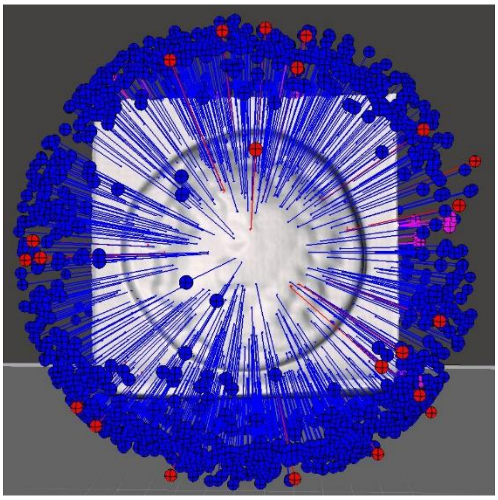


Fig 13.5 The imported Die on Meshmixer
Ref. Screenshots taken by Meshmixer

The part will be subject to inspection for identifying and repairing the holes for making it watertight as shown at Fig.13.6-13.7.



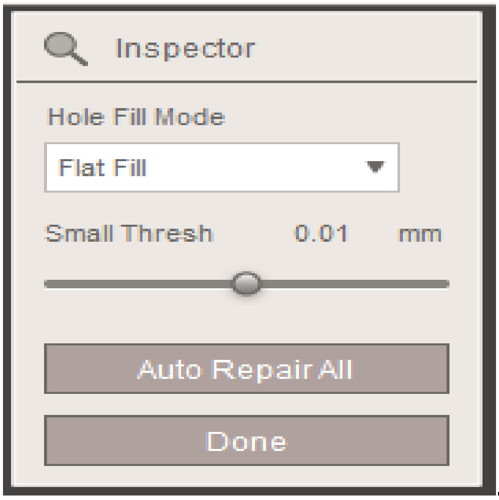


Fig 13.6 Inspector Command depicting that the model is not watertight

Fig 13.7 Automatic Repair of the holes

Ref. Screenshots taken by Meshmixer

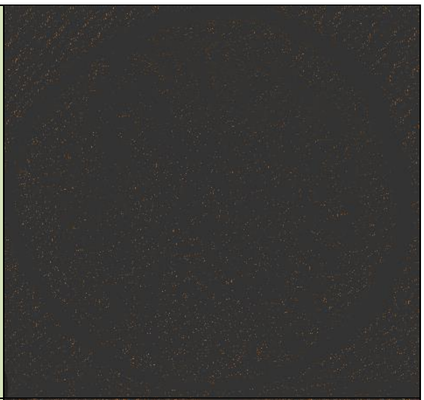
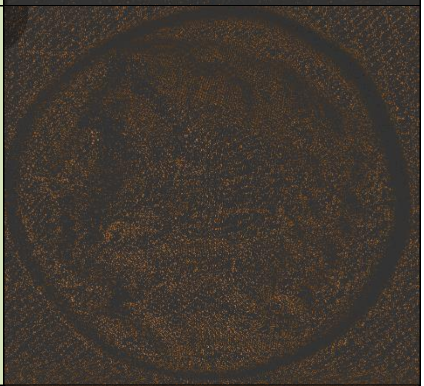
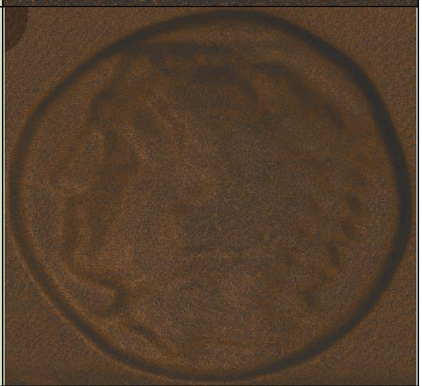
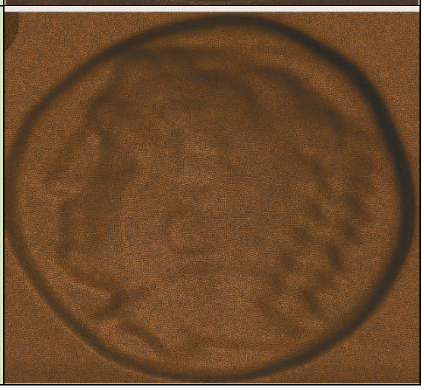
After the inspection and repair of the part is finished the part will be converted to solid using the “convert to solid” command as shown at Fig.13.8.

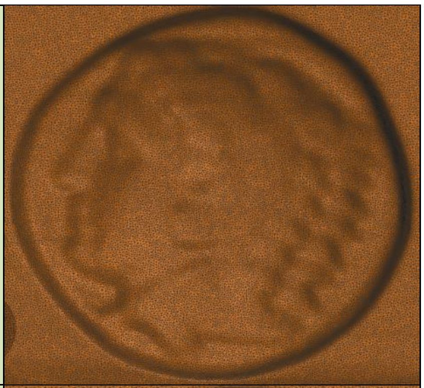
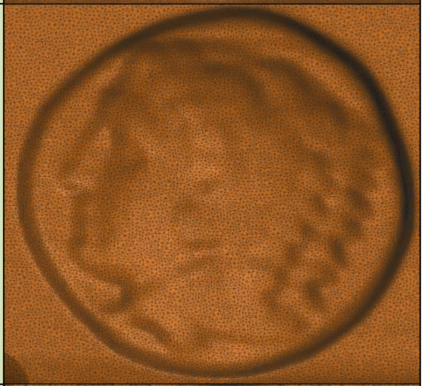
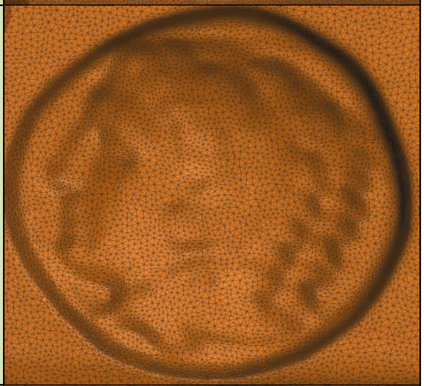
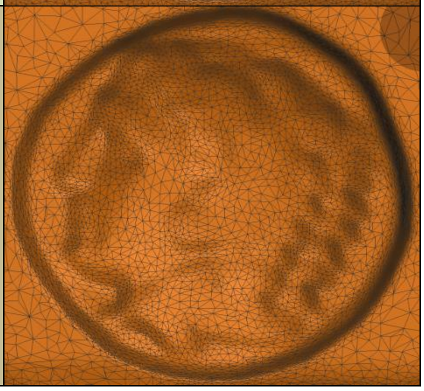
Fig 13.8 Convert to solid option
Ref. Screenshots taken by Meshmixer

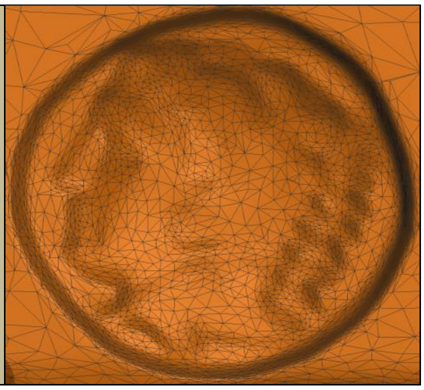
With the part being solid the next step is the reduction process as depicted at Table 13.2

Table 13.2 Positive Die grid and file size after Reduce process

	Vertices/ Triangles	**Wireframe**

Default Values	2896257/ 5792586	
Reduce No 1	1448110/ 2896292	
Reduce No 2	724037/ 1448146	
Reduce No 3	362000/ 724072	

Reduce No 4	180982/ 362036	
Reduce No 5	90473/ 181018	
Reduce No 6	45218/ 90508	
Reduce No 7	22591/ 45254	

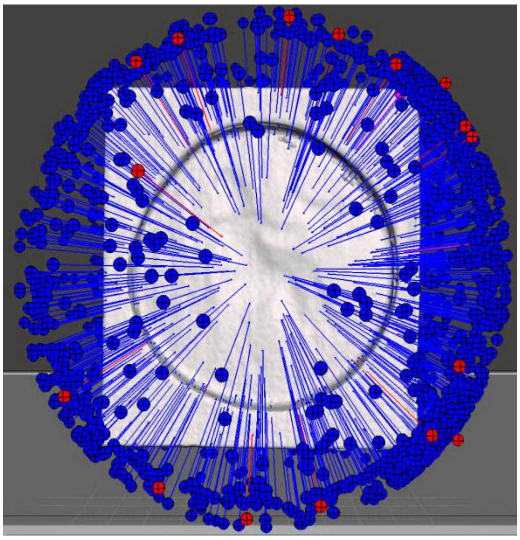
Reduce No 8 Fail	**11277/ 22626**	

13.3. FDM negative die manipulation process

The negative die is imported on Meshmixer as shown at Fig.13.9

Fig 13.9 The imported Die on Meshmixer
Ref. Screenshots taken by Meshmixer

The part will be subjected to inspection for identifying and repairing the holes and by this way it will be converted to a watertight model as shown at Fig.13.10-13.11.



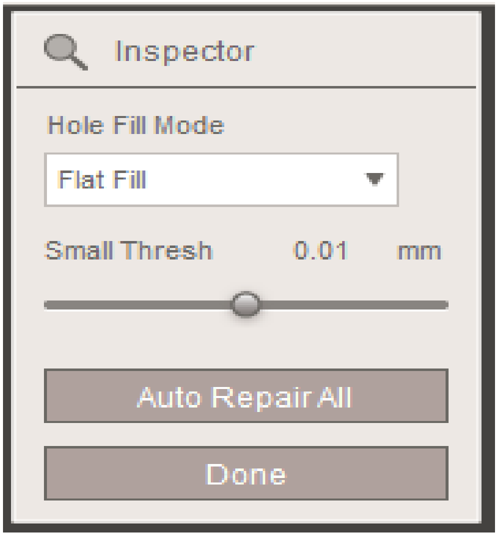


Fig 13.10 Inspector Command depicting that the model is not watertight

Fig 13.11 Automatic Repair of the holes

Ref. Screenshots taken by Meshmixer

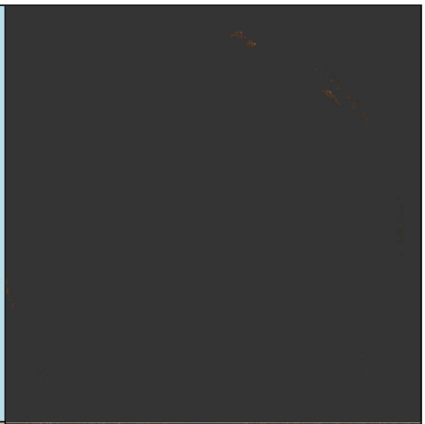
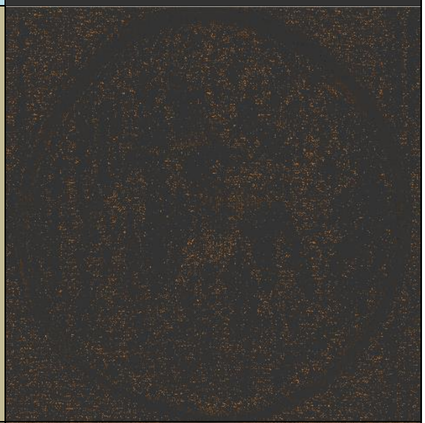
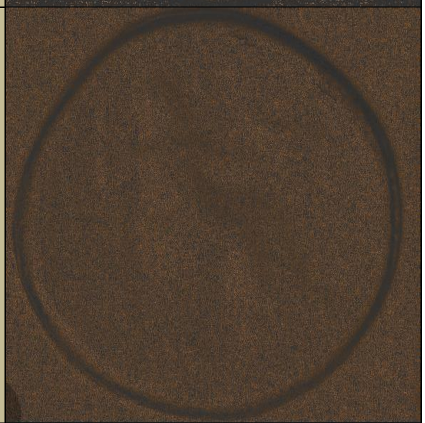
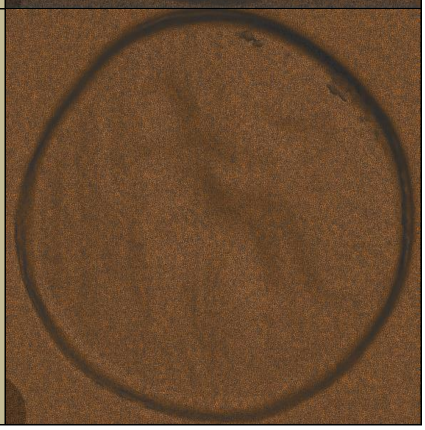
With the inspection and repair of the part done it will then be converted to solid using the "convert to solid" command as shown at Fig.13.12.

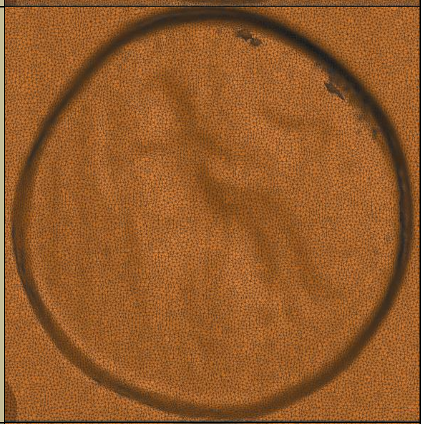
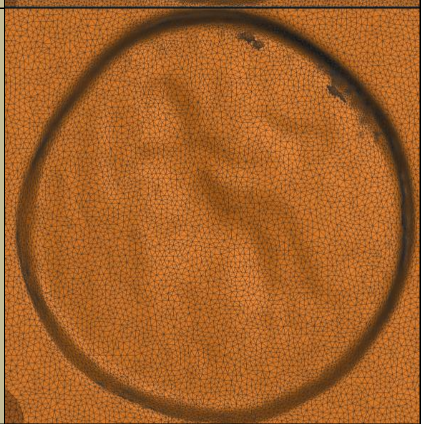
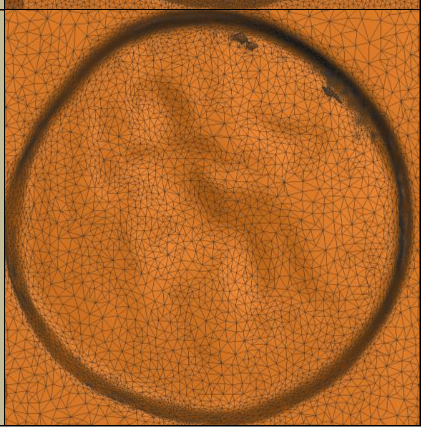
Fig 13.12 Convert to solid option
Ref. Screenshots taken by Meshmixer

With the part being solid the next step is the reduction process as depicted at Table 13.3

Table 13.3 Negative Die Grid and file size after Reduce process

	Vertices/ Triangles	**Wireframe**

Default Values	**3717750/ 7430213**	
Reduce No 1	**1858852/ 3717724**	
Reduce No 2	**929421/ 1858862**	
Reduce No 3	**464705/ 929430**	

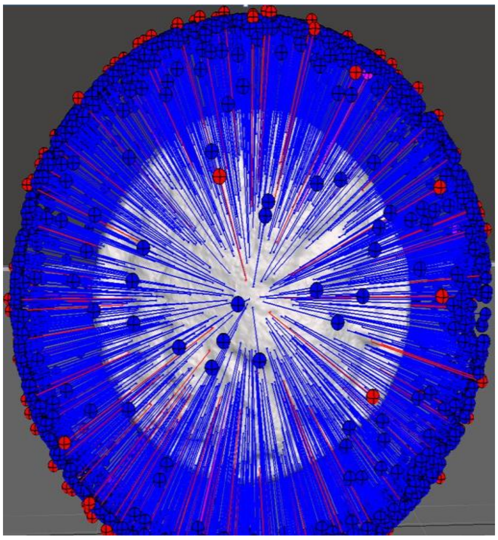
Reduce No 4	232347/ 464714	
Reduce No 5	116168/ 232356	
Reduce No 6	58079/ 116178	
Reduce No 7 Fail	29034/ 58088	

13.4. SLA coin manipulation process

The SLA coin is imported on Meshmixer as shown at Fig.13.12

Fig 13.12 The imported coin on Meshmixer
Ref. Screenshots taken by Meshmixer

The part will be subjected to inspection for identifying and repairing the holes and by this way it will be converted to a watertight model as shown at Fig.13.13-13.14.



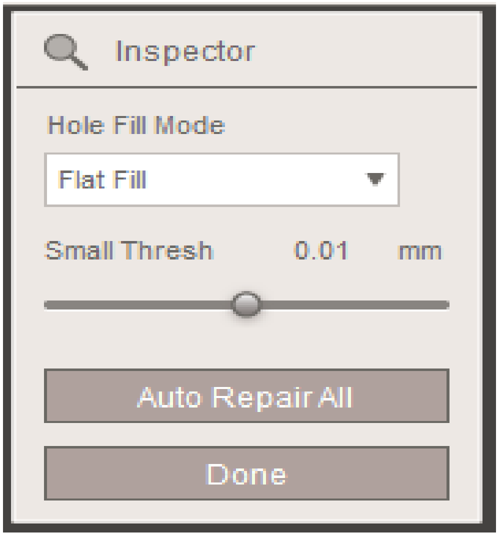


Fig 13.13 Inspector Command depicting that the model is not watertight

Fig 13.14 Automatic Repair of the holes

Ref. Screenshots taken by Meshmixer

With the inspection and repair of the part done it will then be converted to solid using the "convert to solid" command as shown at Fig.13.15.

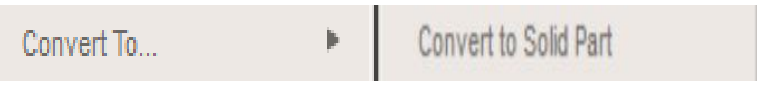
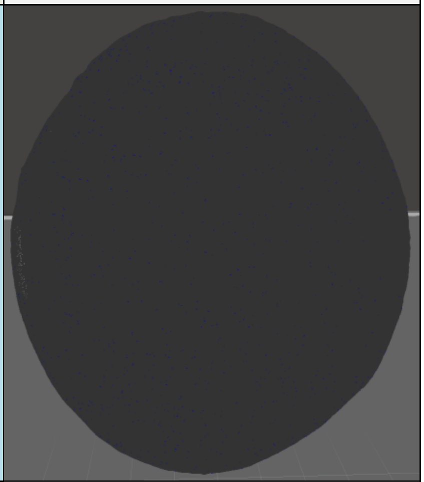
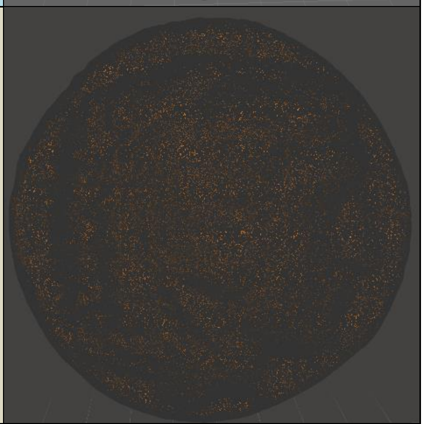
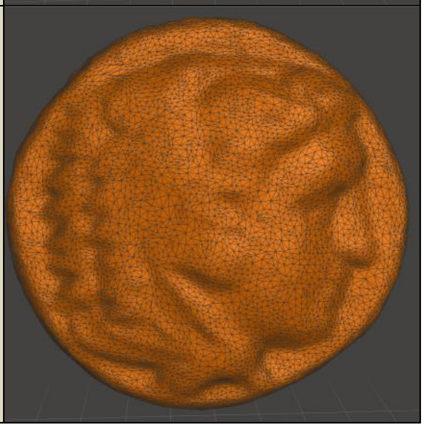


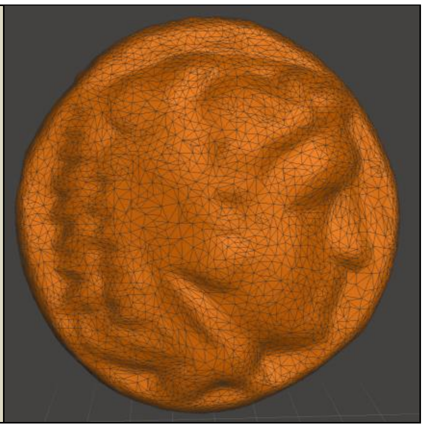
Fig 13.15 Convert to solid option
Ref. Screenshots taken by Meshmixer

With the part being solid the next step is the reduction process as depicted at Table 13.4

Table 13.4 SLA coin grid and file size after Reduce process

	Vertices/ Triangles	**Wireframe**
Default Values	**1922505/ 3833952**	
Reduce No 1	**961247/ 1922490**	
Reduce No 2	**480624/ 961244**	

Reduce No 3	**240413/ 480622**	
Reduce No 4	**120157/ 240310**	
Reduce No 5	**60079/ 120154**	
Reduce No 6	**30040/ 60076**	

Reduce No 7 Fail	**15021/ 30038**	

13.5. SLA positive die manipulation process

The SLA positive die is imported on Meshmixer as shown at Fig.13.16

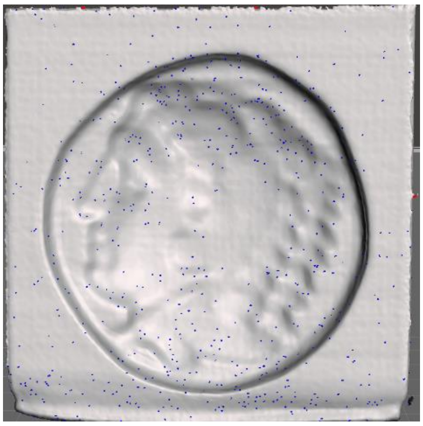


Fig 13.16 The imported Die on Meshmixer
Ref. Screenshots taken by Meshmixer

The part will be subject to inspection for identifying and repairing the holes for making it watertight as shown at Fig.13.17-13.18.

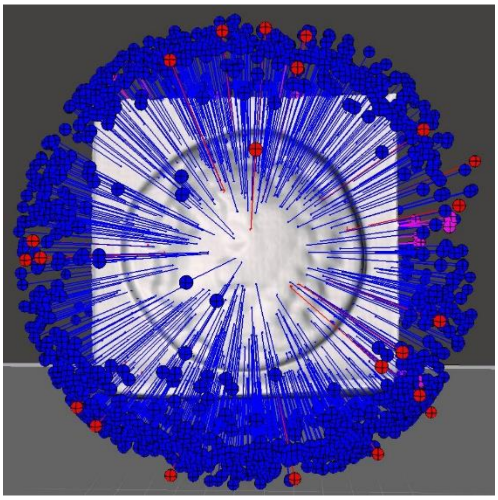


Fig 13.17 Inspector Command depicting that the model is not watertight

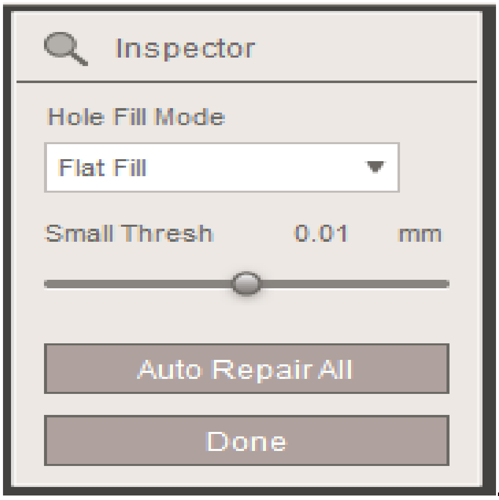


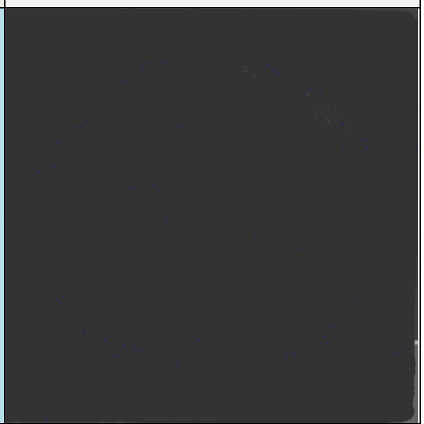
Fig 13.18 Automatic Repair of the holes

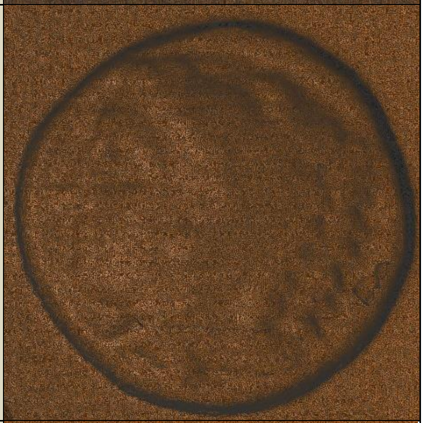
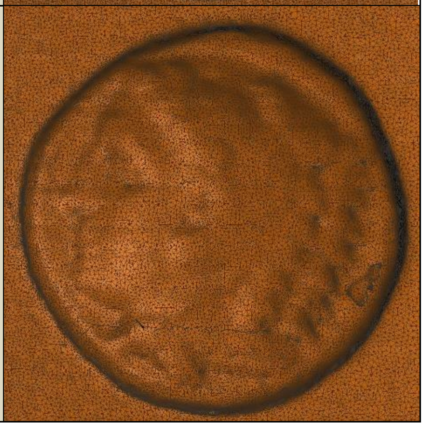
Ref. Screenshots taken by Meshmixer

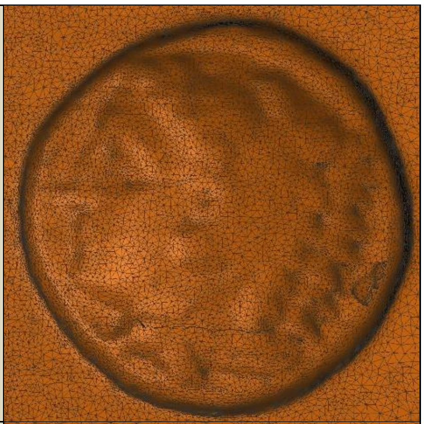
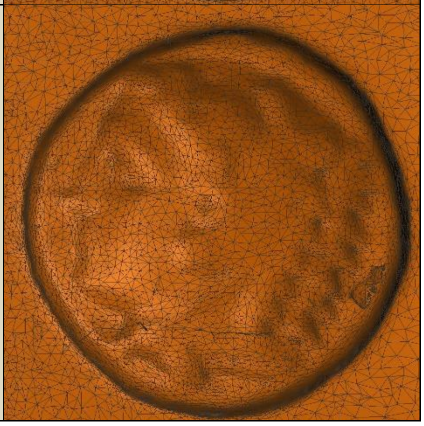
After the inspection and repair of the part is finished the part will be converted to solid using the “convert to solid” command as shown at Fig.13.19.

Fig 13.19 Convert to solid option
Ref. Screenshots taken by Meshmixer

With the part being solid the next step is the reduction process as depicted at Table 13.5

	Vertices/ Triangles	**Wireframe**
Default Values	**2427624/ 4855248**	
Reduce No 1	**1213820/ 2427640**	

Reduce No 2	606910/ 1213820	
Reduce No 3	303455/ 606910	
Reduce No 4	151727/ 303454	
Reduce No 5	75863/ 151726	

Reduce No 6	**37931/ 75862**	
Reduce No 7 Fail	**18965/ 37930**	

13.6. SLA negative die manipulation process

The SLA negative die is imported on Meshmixer as shown at Fig.13.20

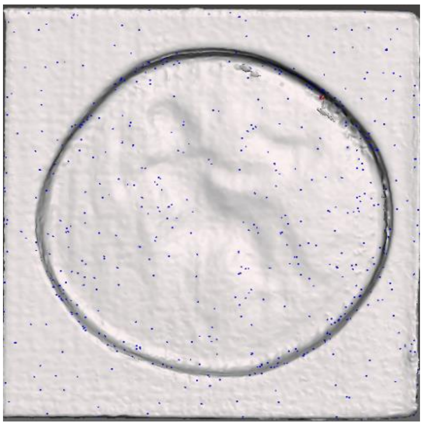
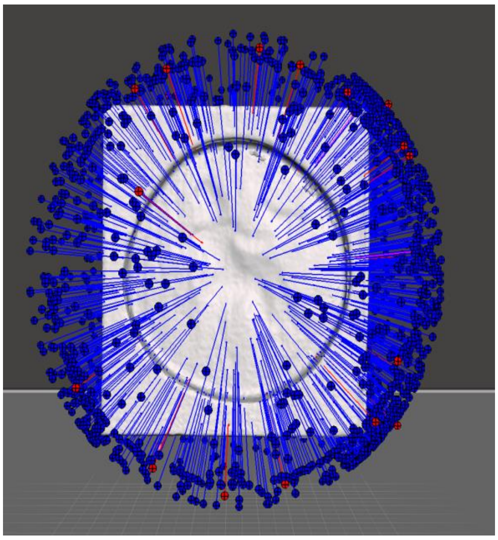


Fig 13.20 The imported SLA negative die on Meshmixer

The part will be subjected to inspection for identifying and repairing the holes and by this way it will be converted to watertight model as shown at Fig.13.21-13.22.



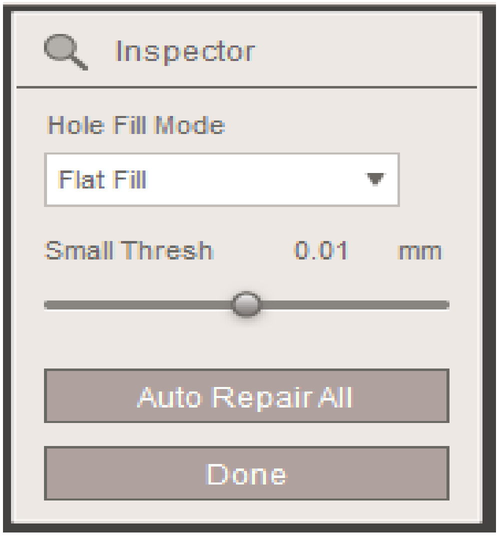


Fig 13.21 Inspector Command depicting that the model is not watertight

Fig 13.22 Automatic Repair of the holes

Ref. Screenshots taken by Meshmixer

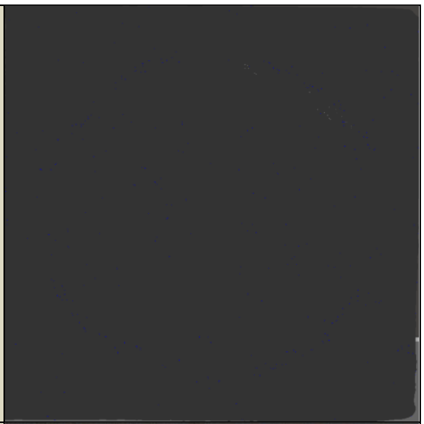
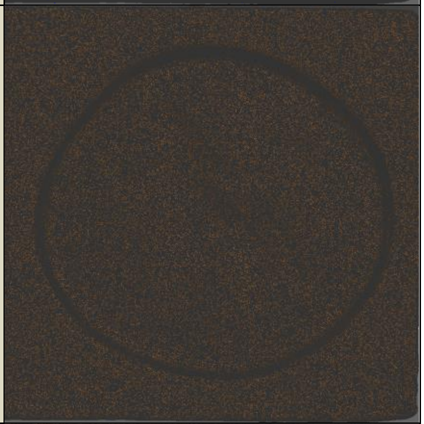
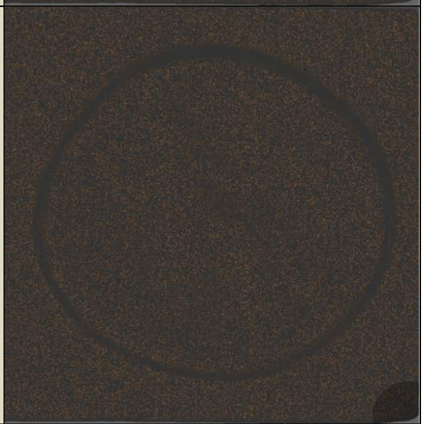
With the inspection and repair of the part done it will then be converted to solid using the "convert to solid" command as shown at Fig.13.23.

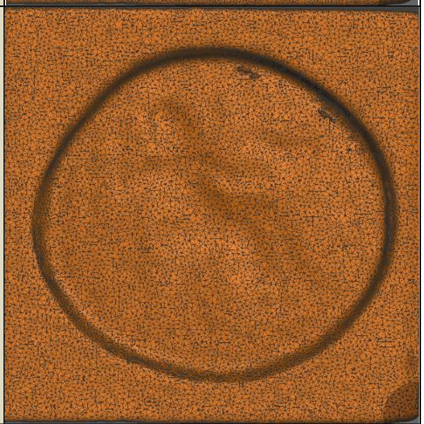
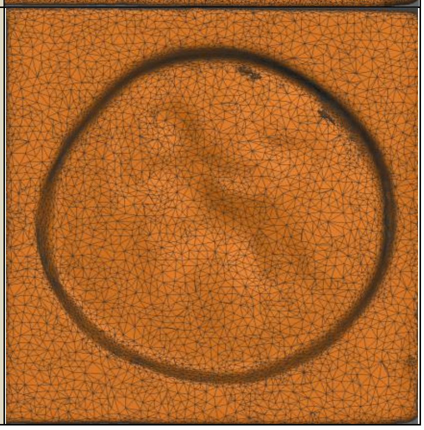
Fig 13.23 Convert to solid option
Ref. Screenshots taken by Meshmixer

With the part being solid the next step is the reduction process as depicted at Table 13.6

Table 13.6 SLA coin grid and file size after Reduce process

	Vertices/ Triangles	**Wireframe**

Default Values	**3717750/ 7430213**	
Reduce No 1	**1858852/ 3717724**	
Reduce No 2	**929421/ 1858862**	
Reduce No 3	**464705/ 929430**	

Reduce No 4	232347/ 464714	
Reduce No 5	116168/ 232356	
Reduce No 6	58079/ 116178	
Reduce No 7 Fail	29034/ 58088	

13.7. Original coin manipulation process

The original coin data are imported on Meshmixer as shown at Fig.13.24

Fig 13.24 The imported original coin on Meshmixer
Ref. Screenshots taken by Meshmixer

The part will be subjected to inspection for identifying and repairing the holes and by this way it will be converted to a watertight model as shown at Fig.13.25-13.26.

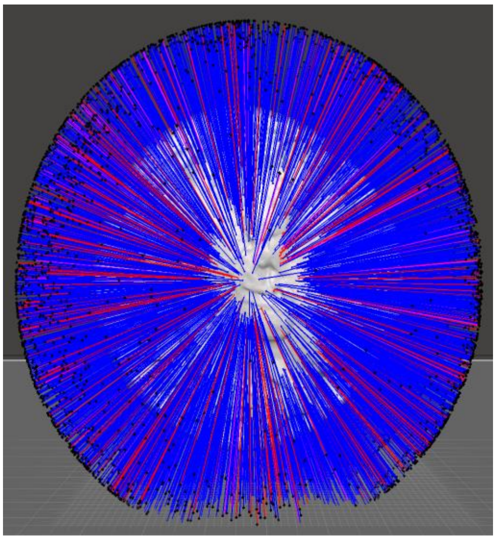


Fig 13.25 Inspector Command depicting that the model is not watertight

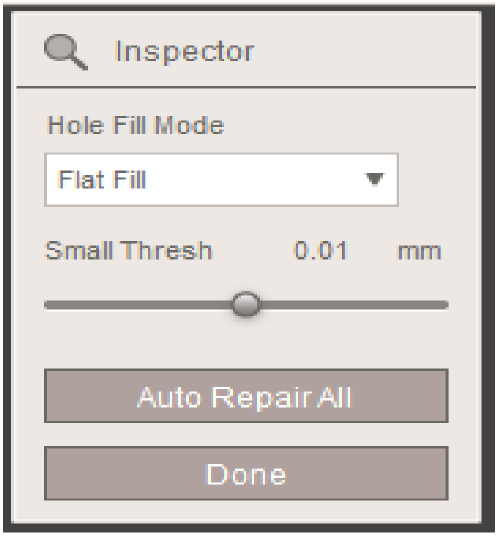


Fig 13.26 Automatic Repair of the holes

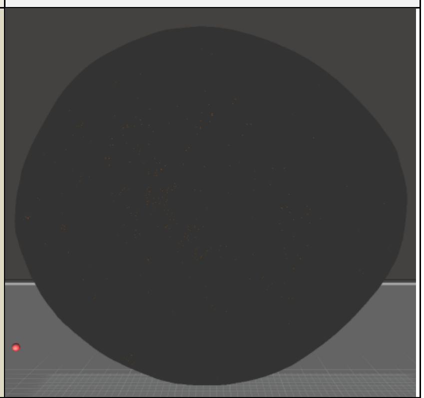
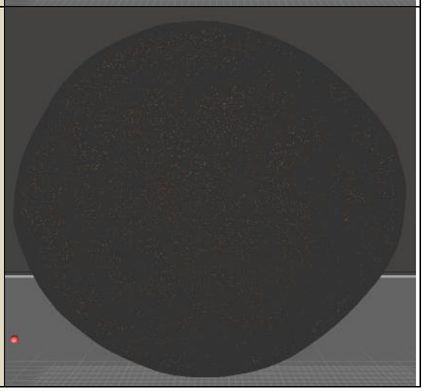
Ref. Screenshots taken by Meshmixer

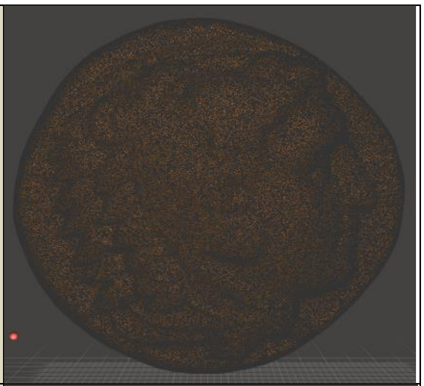
With the inspection and repair of the part done it will then be converted to solid using the “convert to solid” command as shown at Fig.13.27.

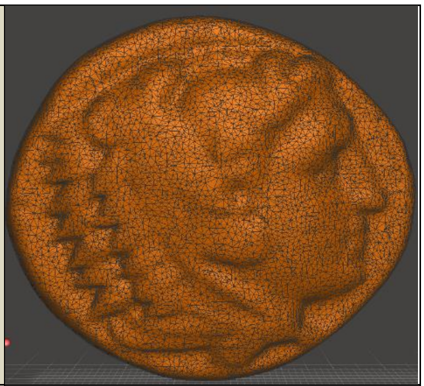
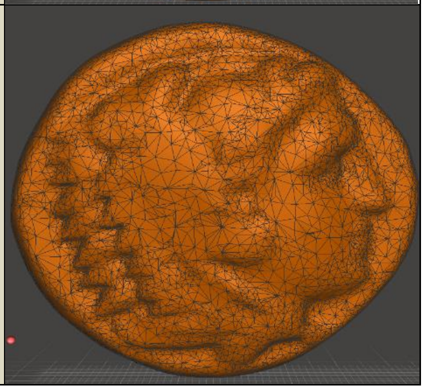
Fig 13.27 Convert to solid option
Ref. Screenshots taken by Meshmixer

With the part being solid the next step is the reduction process as depicted at Table 13.7

Table 13.7 SLA coin grid and file size after Reduce process

	Vertices/ Triangles	Wireframe
Default Values	**1895118/ 3790228**	
Reduce No 1	**947561/ 1895114**	

Reduce No 2	**473782/ 947556**	
Reduce No 3	**236893/ 473778**	
Reduce No 4	**118448/ 236888**	
Reduce No 5	**59226/ 118444**	

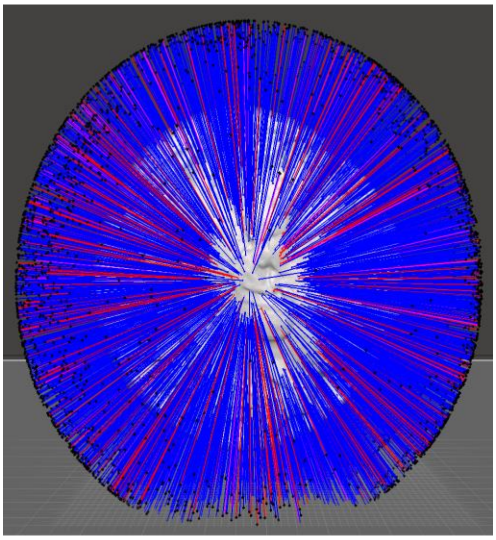
Reduce No 6	**29615/ 59222**	
Reduce No 7 Fail	**14809/ 29610**	

13.8. Plaster Coin manipulation process

The original coin data are imported on Meshmixer as shown at Fig.13.28

Fig 13.28 The imported original coin on Meshmixer
Ref. Screenshots taken by Meshmixer

The part will be subjected to inspection for identifying and repairing the holes and by this way it will be converted to a watertight model as shown at Fig.13.29-13.30.



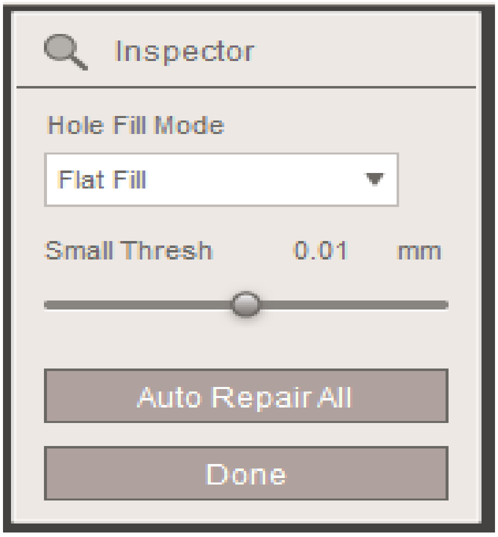


Fig 13.29 Inspector Command depicting that the model is not watertight

Fig 13.30 Automatic Repair of the holes

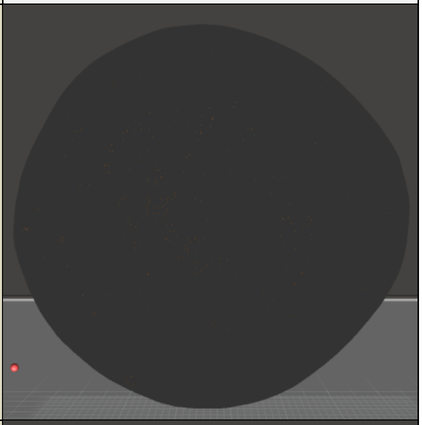
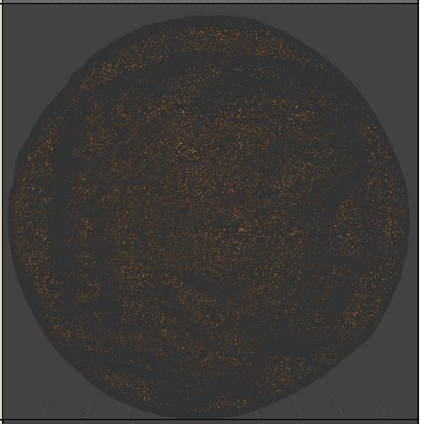
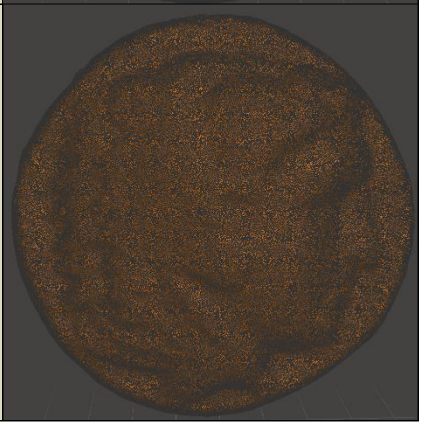
Ref. Screenshots taken by Meshmixer

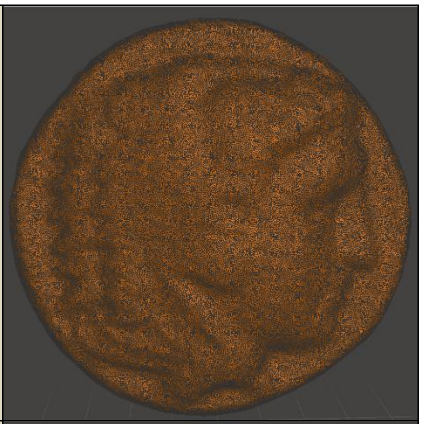
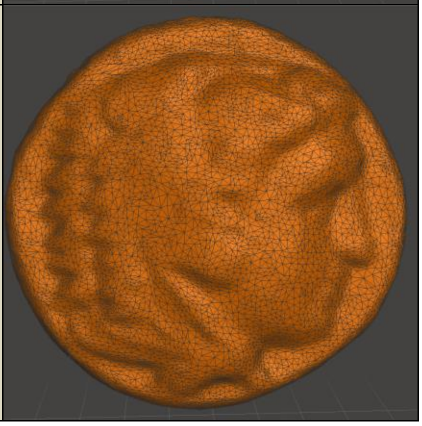
With the inspection and repair of the part done it will then be converted to solid using the “convert to solid” command as shown at Fig.13.31.

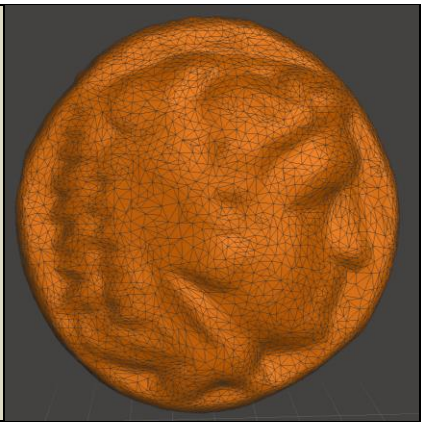
Fig 13.31 Convert to solid option
Ref. Screenshots taken by Meshmixer

With the part being solid the next step is the reduction process as depicted at Table 13.8

Table 13.8 Plaster coin grid and file size after Reduce process

	Vertices/ Triangles	Wireframe
Default Values	**1137216/ 2274124**	
Reduce No 1	**568608/ 1137062**	
Reduce No 2	**284304/ 568531**	

Reduce No 3	**142152/ 284265**	
Reduce No 4	**71076/ 142132**	
Reduce No 5	**35538/ 71066**	
Reduce No 6	**17769/ 35533**	

Reduce No 7 Fail	8885/ 17766	

Conclusions

From the iterations that took place it's clear that the mesh of a scanned file results at a significant increment regarding file size, and by the manipulation process the mesh of the coins and dies regenerated more smoothly so that the details of the iconography to be preserved..At Table 7 the final file size in comparison to the initial of each coin and die is depicted.

Table 7 File size manipulation through iterative reduction of mesh triangles

	Initial *stl file size (MB)	Initial *stl file size (MB)
Original Coin	731.5	1.41
FDM Coin	700.1	2.66
SLA Coin	754.536	2.86
Plaster Coin	412.1	1.6
FDM Positive Die	1147.6	2.15
FDM Negative Die	1480.7	2.76
SLA Positive Die	2203.2	3.71
SLA Negative Die	3103.4	5.53

14. DEVIATION ANALYSIS

The STL files ob**tained by Meshmixer** will now be imported to Artec 11 professional. The aim of the deviation analysis is to compare the surfaces of the FDM-SLA coins compared to the original one and each of the SLA-FDM dies accordingly compared to each other. The process of the deviation analysis will be described and after that the conclusions of the analysis will follow.

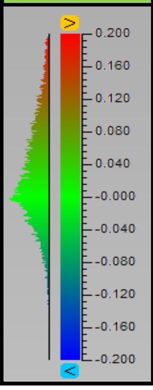
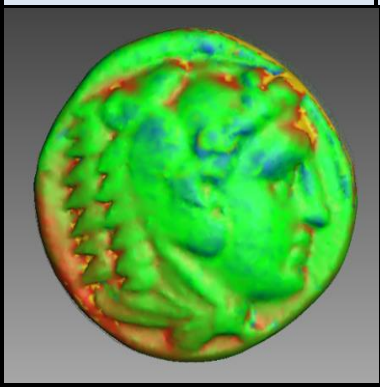
14.1. Process

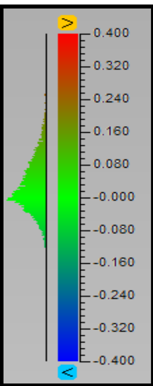
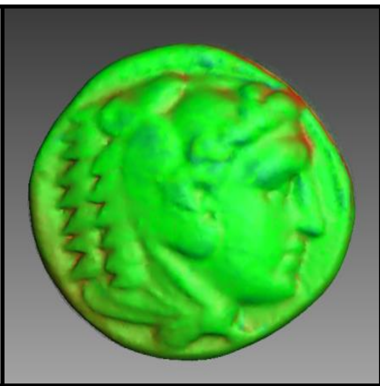
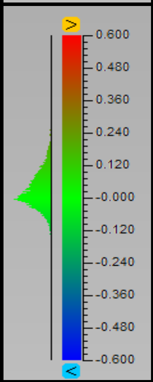
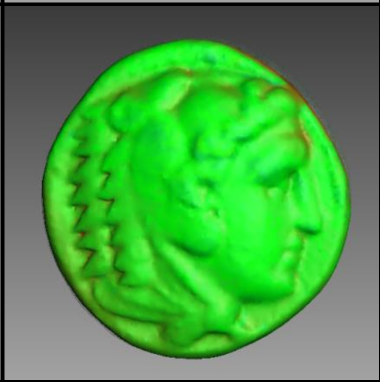
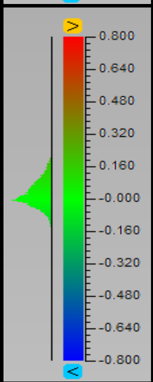
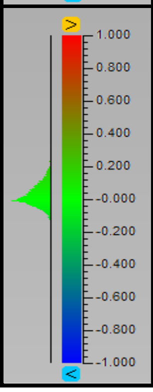
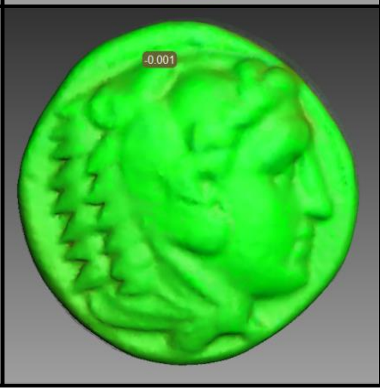
The original coin and the FDM replica will be imported in Artec Studio. For conducting the analysis the two coins should be aligned with use of pins at obvious points at first and after that with use of measurements option the surfaces differences will be calculated. The same process will take place with the SLA coin and the plaster one each one of those compared to the original coin. After that the same procedure will ake place for the FDM and SLA positive and negative dies. Due to the large number of the parts to be compared the process will take place by the following order:

- **Align**
- **Measure**

The group of measurements will take place with a start error scale of 0.1mm at all coins and dies and will be increased until each coin-die to appear in green color something that will depict that the surface differences will be within the chosen error scale.

14.2. Original-FDM coin

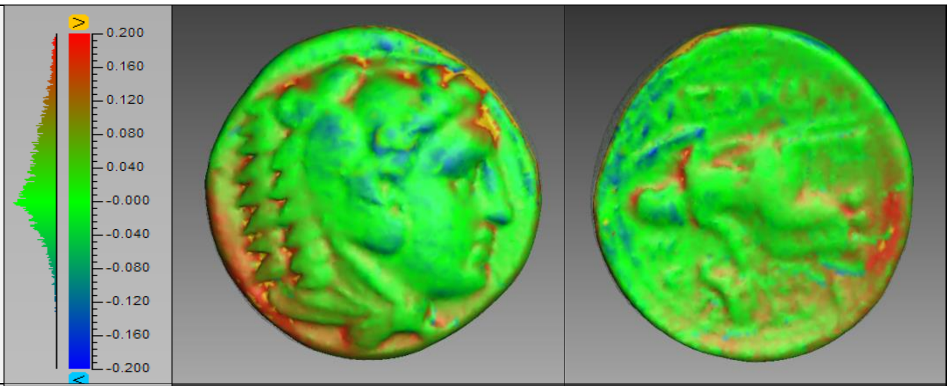
Error scale step (mm)	Error Scale	Front View	Back View
0.2			

0.4			
0.6			
0.8			
1			

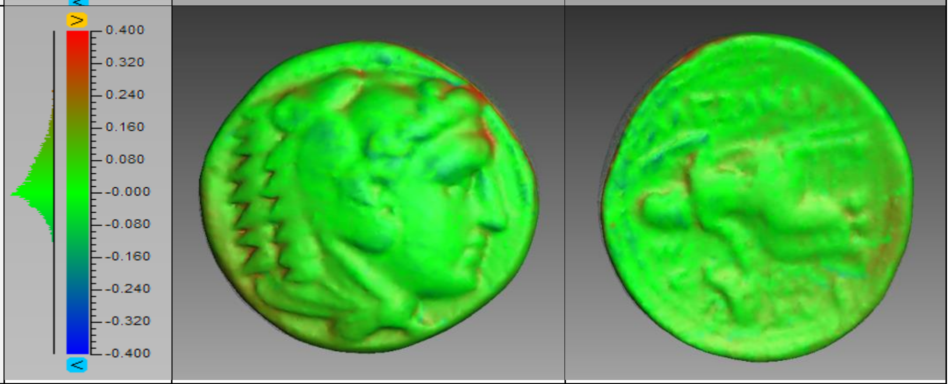
14.3. Original-SLA coin

Error scale step (mm)	Error Scale	Front View	Back View

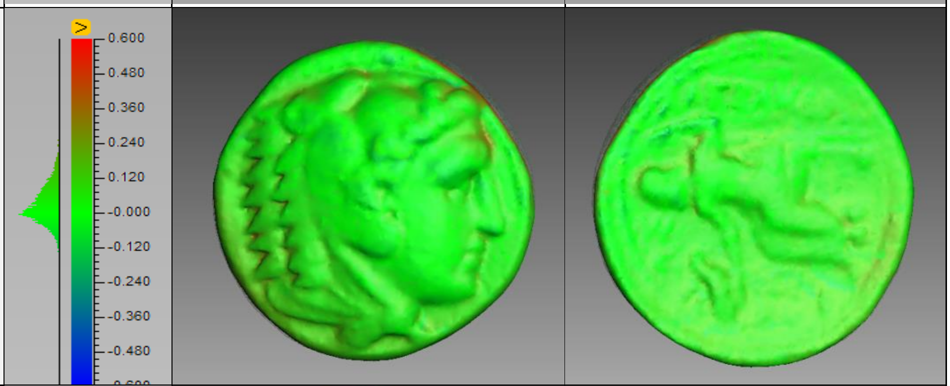
0.2


0.200
0.160
0.120
0.080
0.040
-0.000
-0.040
-0.080
-0.120
-0.160
-0.200

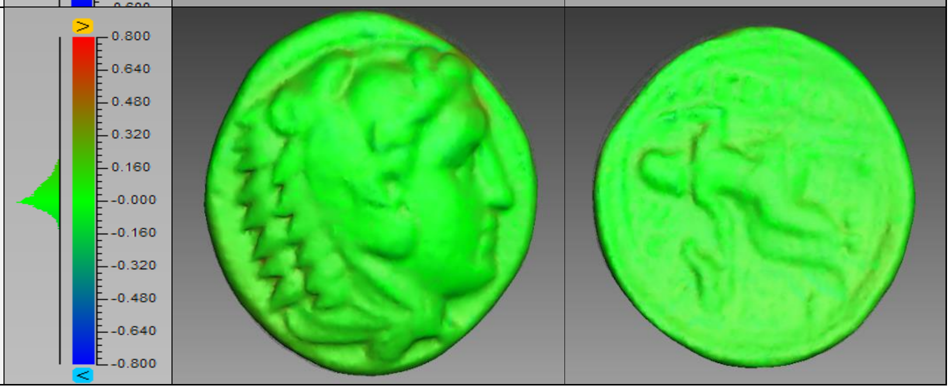
0.4

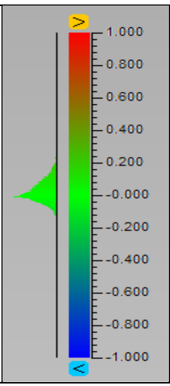
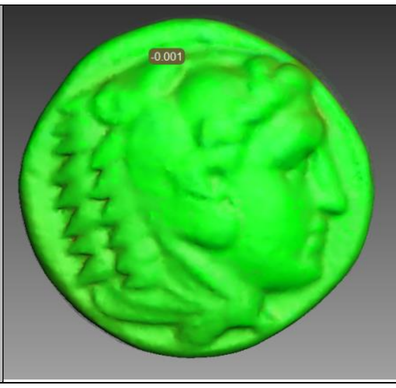

0.400
0.320
0.240
0.160
0.080
-0.000
-0.080
-0.160
-0.240
-0.320
-0.400

0.6

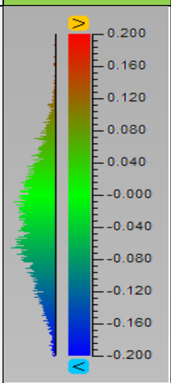
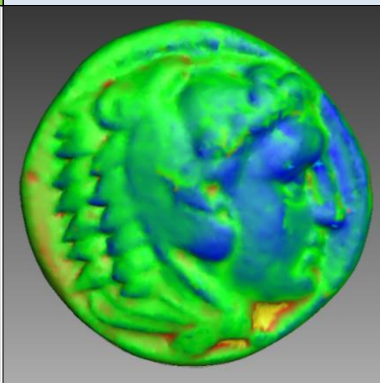
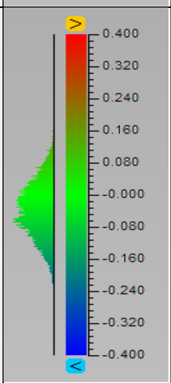
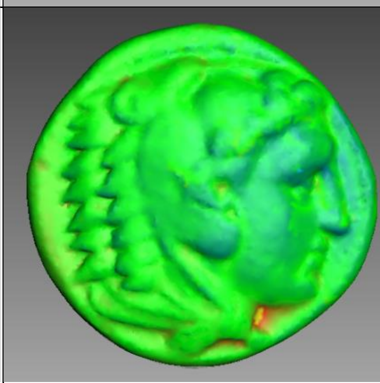
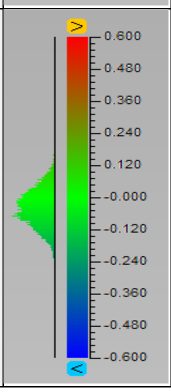
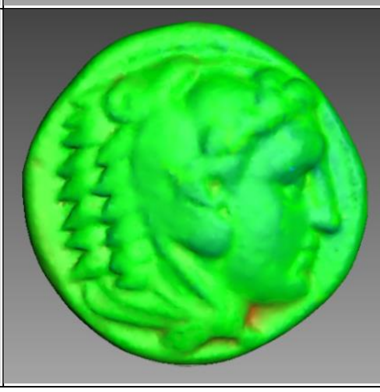

0.600
0.480
0.360
0.240
0.120
-0.000
-0.120
-0.240
-0.360
-0.480

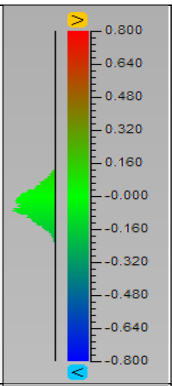
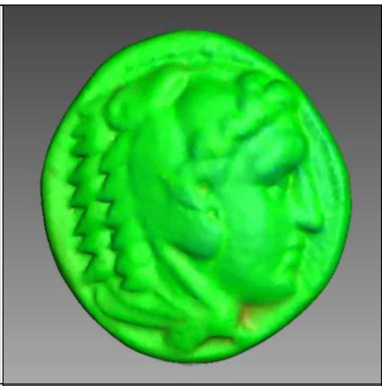
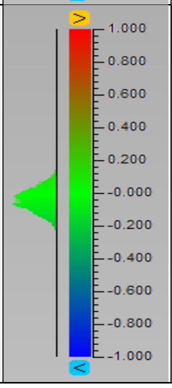
0.8


0.800
0.640
0.480
0.320
0.160
-0.000
-0.160
-0.320
-0.480
-0.640
-0.800

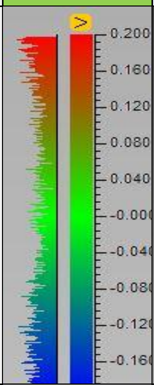
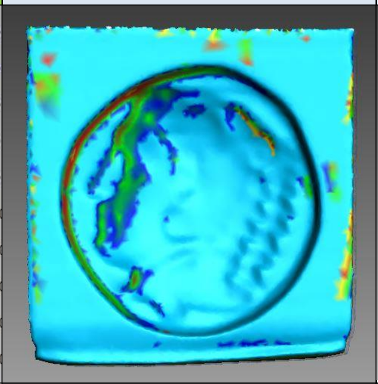
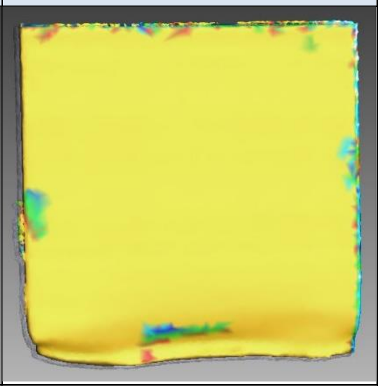
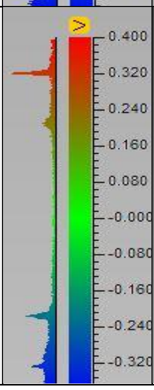
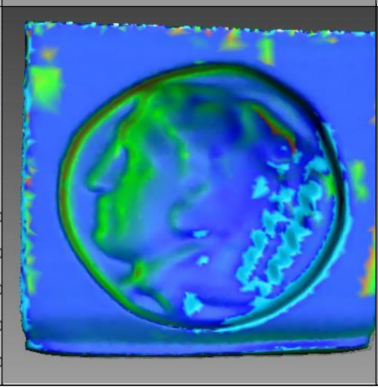
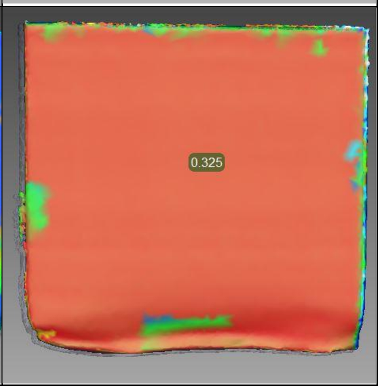
1			

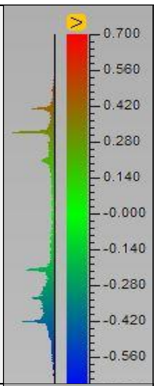
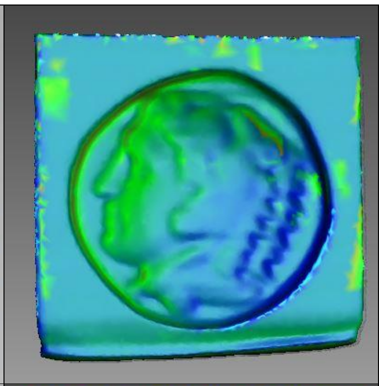
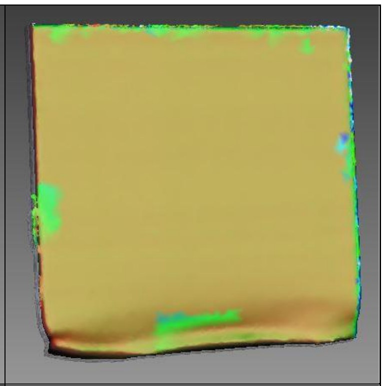
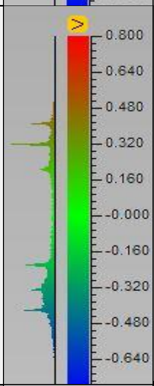
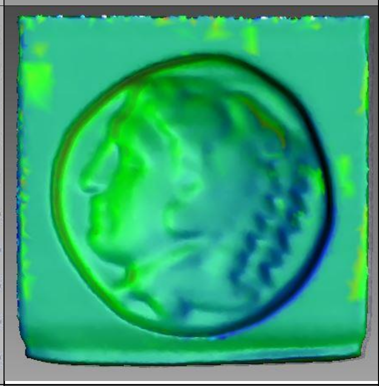
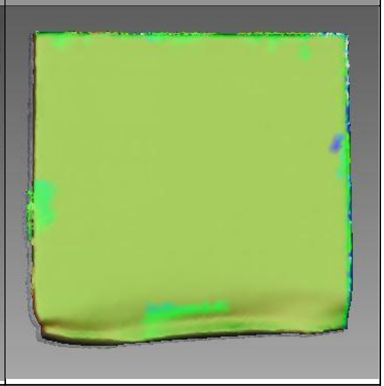
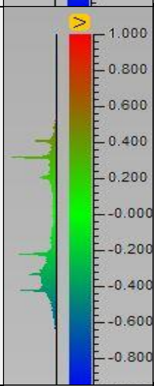
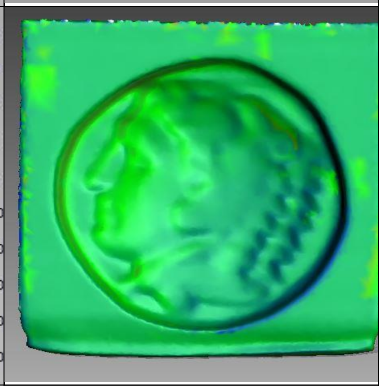
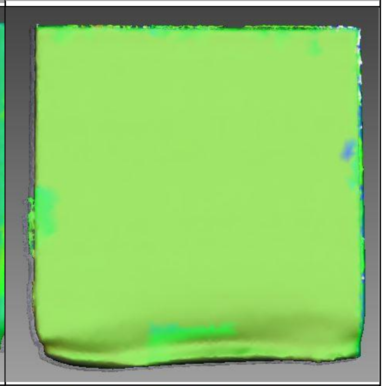
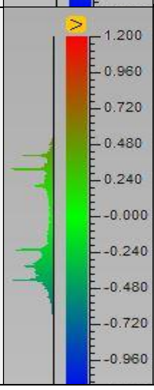
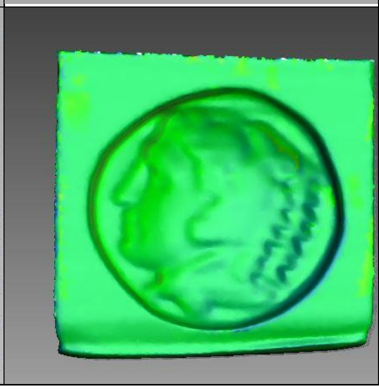
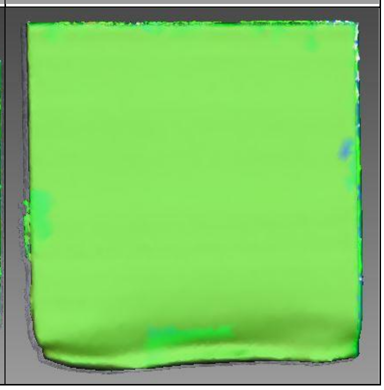
14.4. Original-Plaster coin

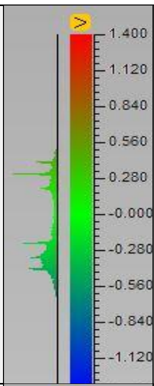
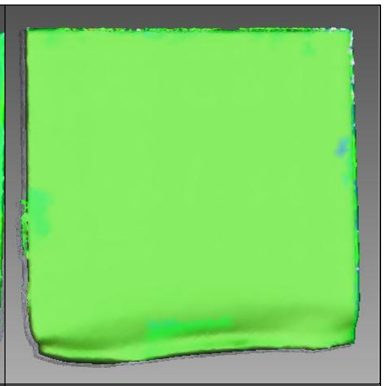
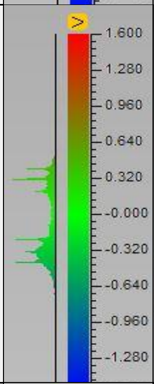
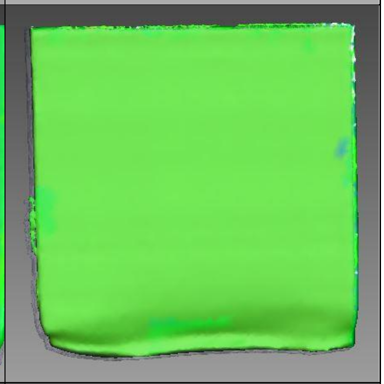
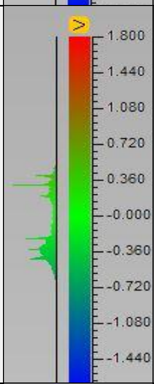
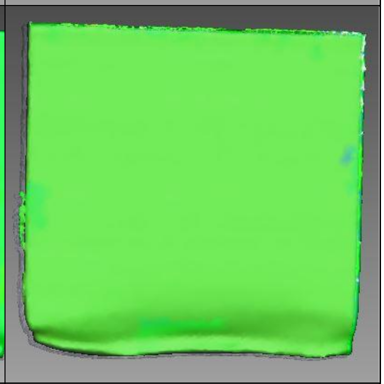
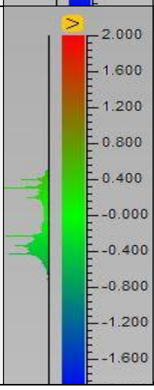
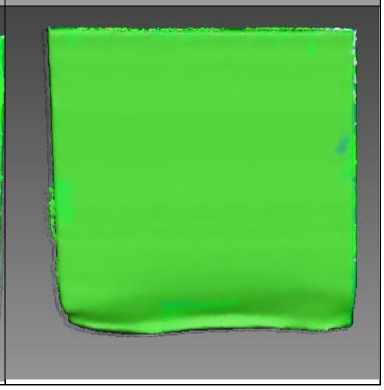
Error scale step (mm)	Error Scale	Front View	Back View
0.2			
0.4			
0.6			

0.8			
1			

14.5. Positive FDM-SLA dies

Error scale step (mm)	Error Scale	Front View	Back View
0.2			
0.4			

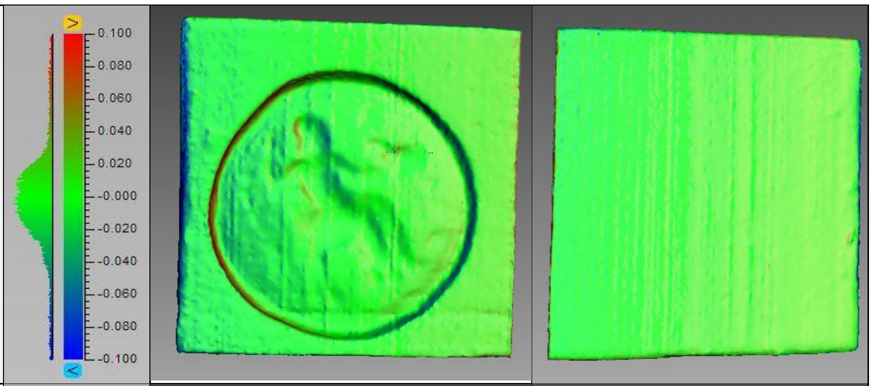
0.6	 0.700 0.560 0.420 0.280 0.140 -0.000 -0.140 -0.280 -0.420 -0.560		
0.8	 0.800 0.640 0.480 0.320 0.160 -0.000 -0.160 -0.320 -0.480 -0.640		
1	 1.000 0.800 0.600 0.400 0.200 -0.000 -0.200 -0.400 -0.600 -0.800		
1.2	 1.200 0.960 0.720 0.480 0.240 -0.000 -0.240 -0.480 -0.720 -0.960		

1.4			
1.6			
1.8			
2			

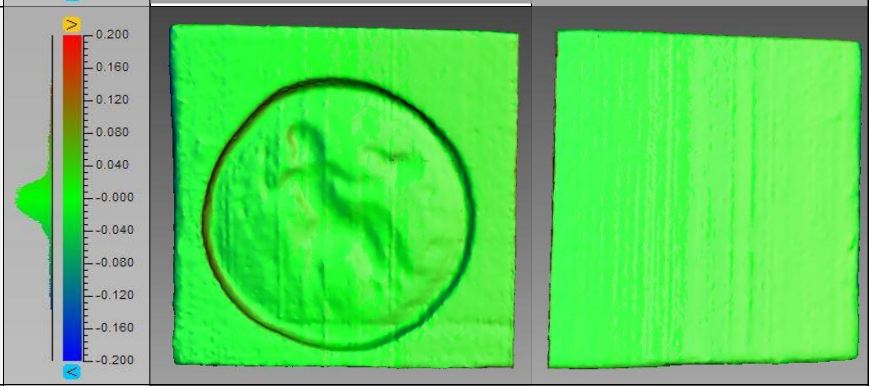
14.6. Negative FDM-SLA dies

Error scale step (mm)	Error Scale	Front View	Back View

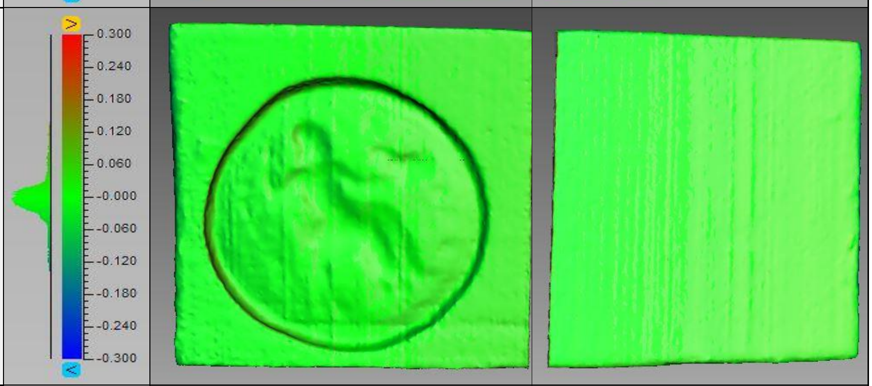
0.1


0.100
0.080
0.060
0.040
0.020
-0.000
-0.020
-0.040
-0.060
-0.080
-0.100

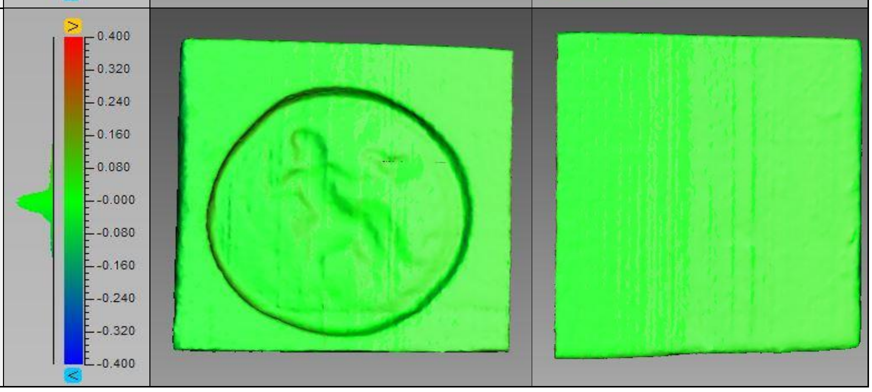
0.2

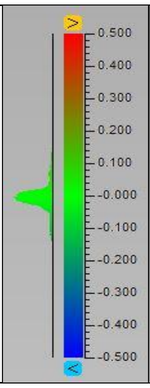
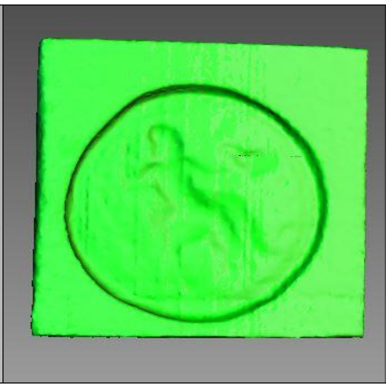
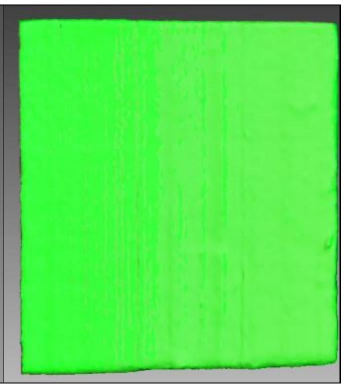

0.200
0.160
0.120
0.080
0.040
-0.000
-0.040
-0.080
-0.120
-0.160
-0.200

0.3


0.300
0.240
0.180
0.120
0.060
-0.000
-0.060
-0.120
-0.180
-0.240
-0.300

0.4


0.400
0.320
0.240
0.160
0.080
-0.000
-0.080
-0.160
-0.240
-0.320
-0.400

0.5			

14.7. Conclusions deriving from the deviation analysis

From the deviation analysis conducted above we see that the FDM-SLA-Plaster coin with an error scale of 0.2 mm are illustrated in green color, meaning that the surface differences compared to the original one are within this limit .Despite that, we see some regions in the coins which extend this error scale boundary as they appear in red color (depicting surface difference up to +0.2mm) and blue color (depicting surface differences up to -0.2 mm).On the other hand the plaster coin with the same error scale limit results in bigger difference than 0.2mm as it appears in blue color in many regions. By error scale increment of 0.4mm the FDM-SLA coins appear in mostly in green color, meaning that they fulfill the set up error scale. The positive FDM-SLA dies with a starting error scale of 0.2mm depict surface differences much more than the chosen error scale boundary as the view appear in azure and yellow color depicting surface differences more than 0.2 mm. When the error scale is set up to 0.4mm the dies views conform to this error scale limit since the color of the surfaces appear in blue and red color showing that the surface differences are within the error scale but on most of the regions reach the maximum boundary value. The dies start to adapt a green color at most of their regions with an error scale of 1.2 mm depicting at this point that the surface differences are located within this limit. Eventually, by the iteration process the total surface differences fulfill the error scale criterion at a value of 1.8mm as at this point the majority of the die’s surfaces appear in green color. On the other hand, the negative dies with an error scale of 0.1 mm include most of the surfaces differences as they have tiny spots depicting surface differences up to 0.1mm.At an error scale boundary of 0.4mm the dies appear in green color meaning that the surface differences between the dies are located within this limit. The differences between the FDM-SLA dies and the FDM coin compared to the original could have derived by the fact that during FDM modeling the parts could have been shrank.

15. CONCLUSIONS AND FURTHER RESEARCH TOPICS

The project was conducted with the aim of depicting the advantages of new methodologies and techniques for replicating an ancient artifact which is sensitive to contact for preservation reasons. The disadvantage of obtaining 3d data by use of Reverse Engineering with non contact methods though is that the manipulation of those data should be carefully post processed later on with Next Engine Scan Studio, Meshmixer and eventually with Artec 11 Professional , especially the align of the multiple scans. If the manipulation of those data is not carefully done, this will result to problems regarding the deviation analysis. The procedure for obtaining 3d data, transfer them in CAD and/ or manipulation software and fabricate an object could be further exploited not only with FDM or SLA Additive Manufacturing processes but also by use of Selective Laser Sintering (SLS). Furthermore, besides Additive Manufacturing methods subtractive methods can be utilized as well, such as Computer Numerical Control (CNC) process.

16. TABLES OF REFERENCE

[1]. Vinesh Raja and Kiran J. Fernandes (Eds.) Reverse Engineering-An Industrial Perspective

[2]. I. Gibson I D. W. Rosen I B. Stucker Additive Manufacturing Technologies-Rapid Prototyping to Direct Digital Manufacturing

[3]. https://all3dp.com/fdm-vs-sla/

[4]. ΤΑ ΕΛΛΗΝΙΚΑ ΝΟΜΙΣΜΑΤΑ -ΤΕΧΝΗ ΚΑΙ ΤΕΧΝΙΚΗ

[5]. https://www.fleur-de-coin.com/articles/modern-minting

[6]. http://www.calgarycoin.com/reference/fakes/cast.htm

[7].ΑΡΓΟΛΙΚΗ ΑΡΧΕΙΑΚΗ ΒΙΒΛΙΟΘΗΚΗ ΙΣΤΟΡΙΑΣ ΚΑΙ ΠΟΛΙΤΙΣΜΟΥhttps://argolikivivliothiki.gr/2011/05/16/%CF%84%CE%BF-%CE%BD%CF%8C%CE%BC%CE%B9%CF%83%CE%BC%CE%B1-

%CF%83%CF%84%CE%BF%CE%BD-
%CE%B1%CF%81%CF%87%CE%B1%CE%AF%CE%BF-
%CE%B5%CE%BB%CE%BB%CE%B7%CE%BD%CE%B9%CE%BA%CF%8C-
%CE%BA%CF%8C%CF%83%CE%BC%CE%BF/

[8].ΑΡΧΑΙΩΝΤΟΠΟΣhttps://theancientwebgreece.wordpress.com/2015/03/17/%CE%B7-%CE%B1%CF%81%CE%B3%CF%85%CF%81%CE%AE-%CE%BD%CE%BF%CE%BC%CE%B9%CF%83%CE%BC%CE%B1%CF%84%CE%BF%CE%BA%CE%BF%CF%80%CE%AF%CE%B1-%CF%84%CE%BF%CF%85-%CE%BC%CE%B5%CE%B3%CE%AC%CE%BB%CE%BF%CF%85/